

UNCLASSIFIED

AD 4 2 2 1 3 6

DEFENSE DOCUMENTATION CENTER

FOR

SCIENTIFIC AND TECHNICAL INFORMATION

CAMERON STATION, ALEXANDRIA, VIRGINIA



UNCLASSIFIED

NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.

AD No. 422136

DDC FILE COPY

DESCRIPTION OF THE
PROCEDURES AND EQUIPMENT
FOR THE SUPPRESSION AND MITIGATION
OF
ELECTROMAGNETIC INTERFERENCE VOLTAGE
TO
ACCEPTABLE LEVELS,

CONTRACT Noy-88454
DEPARTMENT OF THE NAVY
BUREAU OF YARDS AND DOCKS
WASHINGTON 25, D. C.

AIR FORCE
BALLISTIC MISSILE DIVISION

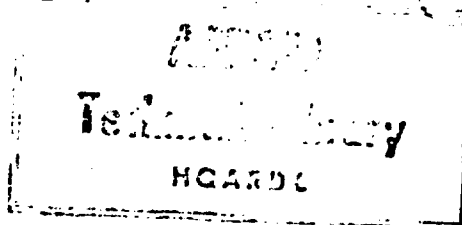
TECHNICAL LIBRARY

Document No. 9-183

Copy No. 1

OUR JOB NO. 656-410

26 JANUARY 1958,



OCT 30 1963

THE HINCHMAN CORPORATION
ENGINEERS
Francis Palms Building
Detroit 1, Michigan

Encl. (1)

8-33390
8-25578

SUMMARY

This report, Phase IV of Contract NOy-88454, is a description of the procedures and equipment for the suppression and mitigation of electromagnetic interference voltage to acceptable levels. The report includes recommendations on power line components, such as, transmission lines and substation equipment for new and existing transmission lines. Transmission lines up to and including 69 Kv are reviewed.

All available published studies by others as well as the knowledge gained from Phases I, II and III, of the subject contract, were utilized in performing this study. A review of Electric Power Utilities design, construction and maintenance procedures was also made and utilized in determining the recommendations of this report. The procedures and equipment were determined from the above study and review for the suppression and mitigation of electromagnetic interference from overhead transmission lines. The conclusions of this report indicate that these methods and procedures to limit the interference from overhead lines to the acceptable level established in Phase III of this contract, are desirable, feasible, and economically justifiable. For many progressive utility companies techniques of interference reduction are routine operations. These techniques of interference reduction are:

1. Proper selection and testing of materials.
2. Proper construction practices.
3. Proper maintenance, including radio patrols.

A section of the report is devoted to the economics of construction and maintenance of overhead transmission lines for minimum interference generation. This type of construction and maintenance is desirable for numerous intangible reasons and is, also, economically feasible. Maintenance aimed at interference reduction is, furthermore, preventive maintenance against power outages. Interference sources, when located and repaired, eliminate "faults" which would probably develop to line outages.

The recommended construction practices are summarized and tabulated in Section 6-19. The complete recommendations are summarized in specification form and are included as Section 11 of the report.

Phase I of Contract NOy-88454 was a review of studies on interference from transmission lines. The report determined that there was not sufficient available published information to establish a level of inherent interference from an acceptable economically designed and maintained transmission line.

Phase II of Contract NOy-88454 was a field study of a number of 41.6 Kv overhead lines. This field work was performed to provide necessary information to develop a criterion test and limits for radio interference, from overhead transmission lines.

Phase III of Contract NOy-88454 was the correlation of the information obtained during the field study, to establish limits of radiated and conducted interference from acceptable economically designed and maintained overhead transmission lines up to 66Kv.

APPRECIATION

The Hinchman Corporation wishes to express sincere appreciation to those persons who lent their time and technical assistance and knowledge to cooperate in the study of electromagnetic interference reduction, Phase IV.

Our grateful appreciation is extended to Commander J. W. Updegrove, CEC, USN, Manager of Engineering Consultants Branch, and to Mr. S. A. Bennett, Project Manager, Bureau of Yards and Docks, Department of the Navy, for their excellent cooperation.

The Detroit Edison Company has given much technical assistance in developing the Phase IV report. We wish to express our deepest appreciation and thanks to Mr. C. R. Landrigan, Executive Vice-President of The Detroit Edison Company for his interest and efforts in the progress of this study. The policy of The Detroit Edison Company in maintaining as low a radio interference level from their overhead lines as is economically feasible has been of great assistance throughout all phases of this study.

The excellent cooperation extended the survey team by Mr. W. G. Meese, Assistant Director of Research, The Detroit Edison Company, under whose direction The Detroit Edison participation was accomplished, is greatly appreciated.

The technical assistance and information furnished by Messrs. R. J. Blanchford and C. J. Crockford of the Overhead Lines Department, Mr. G. E. Greenwood of the Apparatus Division Electrical Systems and Mr. E. A. Elliot of the Engineering Division of Planning and Project Engineering Department is very much appreciated.

TABLE OF CONTENTS

Description of the Procedures and Equipment for the
Suppression and Mitigation of Electromagnetic Interference
Voltage to Acceptable Levels.

| | | <u>Page</u> |
|--------------|--|-------------|
| Summary | | 11 |
| Appreciation | | iv |
| SECTION 1 | Introduction | 1 |
| 1-01 | Overhead Electric Transmission Lines | 1 |
| 1-02 | Radio Interference Concern | 1 |
| 1-03 | Electric Transmission Equipment | 2 |
| SECTION 2 | General | 5 |
| 2-01 | Definition of Radio Interference | 5 |
| 2-02 | Generation of Radio Interference | 5 |
| 2-03 | Propagation of Radio Interference | 6 |
| 2-04 | Frequency Spectrum of Radio Interference | 7 |
| 2-05 | Usual Causes of Radio Interference on Transmission Lines | 7 |
| SECTION 3 | Reasons for Consideration of Interference Reduction | 9 |
| 3-01 | General | 9 |
| 3-02 | Improved Reception | 9 |
| 3-03 | Proper Operation of Electronic Mechanisms | 10 |
| SECTION 4 | Means of Improving Communication Reception | 11 |
| 4-01 | General | 11 |
| 4-02 | Reduction of Interference | 11 |
| SECTION 5 | Sources of Radio Interference on Subtransmission Lines | 12 |
| 5-01 | Definition of Subtransmission Lines | 12 |
| 5-02 | Insulators | 12 |
| 5-03 | Tie Wire | 13 |
| 5-04 | Conductors | 13 |

TABLE OF CONTENTS (CONT)

| | <u>Page</u> |
|---|-------------|
| SECTION 5 (CONT) | |
| 5-05 Poles and Crossarms | 14 |
| 5-06 Hardware | 14 |
| 5-07 Guy Wires | 15 |
| 5-08 Ground Wires | 15 |
| 5-09 Switches | 16 |
| 5-10 Lightning Arresters | 16 |
| 5-11 Pole Line Apparatus | 17 |
| 5-12 Substations | 17 |
| 5-13 Sources of Interference due to Corrosion | 18 |
| 5-14 Sources of Interference due to Contamination | 19 |
| 5-15 Incidence and Nature of Transmission Line Interference | 19 |
| SECTION 6 | |
| Recommended Construction Practices to Reduce Radio Interference | 21 |
| 6-01 General | 21 |
| 6-02 Insulators | 21 |
| 6-03 Tie Wires | 23 |
| 6-04 Conductors | 24 |
| 6-05 Poles and Crossarms | 25 |
| 6-06 Hardware | 25 |
| 6-07 Guy Wires | 26 |
| 6-08 Ground Wires | 27 |
| 6-09 Switches | 27 |
| 6-10 Lightning Arresters | 27 |
| 6-11 Pole Line Apparatus | 28 |
| 6-12 Substation Construction | 28 |
| 6-13 Consideration of Corrosive Conditions | 29 |
| 6-14 Recommended Practices for Porcelain in Contaminated Areas | 33 |
| 6-15 Radio Frequency (r.f.) Choke Coils | 34 |
| 6-16 Attenuation by means of Underground Installation | 36 |
| 6-17 Miscellaneous Items | 36 |
| 6-18 Interference Suppression at the Receiver | 37 |
| 6-19 Summary of Recommendations | 37 |

TABLE OF CONTENTS (CONT)

| | | <u>Page</u> |
|------------|--|-------------|
| SECTION 7 | Detection of Radio Interference | 41 |
| 7-01 | General | 41 |
| 7-02 | Conducted and Radiated Interference | 42 |
| 7-03 | Patrol of the Transmission System | 42 |
| 7-04 | Portable Receiver | 44 |
| 7-05 | Mallet Test | 45 |
| 7-06 | Shaking Wires | 46 |
| 7-07 | Switching Test | 46 |
| SECTION 8 | Maintaining Low Radio Interference Level | 47 |
| 8-01 | General | 47 |
| 8-02 | Performance of Tests | 48 |
| SECTION 9 | Economics of Radio Interference Control | 49 |
| 9-01 | General | 49 |
| 9-02 | Future Construction | 50 |
| 9-03 | Existing Transmission Lines | 50 |
| 9-04 | Transmission Line Patrols | 51 |
| SECTION 10 | Quality Control of Transmission Line Components | 52 |
| 10-01 | General | 52 |
| 10-02 | Method of Measurement | 52 |
| 10-03 | Limits of Interference | 52 |
| 10-04 | Recommendations | 52 |
| SECTION 11 | SUMMARY OF RECOMMENDATIONS IN SPECIFICATION FORM | 53 |
| | DRAWINGS | 58 |
| | BIBLIOGRAPHY | 72 |

SECTION 1. INTRODUCTION

1-01 Overhead Electric Transmission Lines. Through discovery, invention, and engineering application, the engineer has made continually greater use of electricity. Its early use, however, was limited to relatively short distances from the power station because of the low voltage of the distribution circuits. This limitation, for economic reasons, kept the general use of electricity confined to areas where a number of customers could be served from the same power station. The invention of the transformer was revolutionary since it made high voltage and longer transmission distances possible, thus placing electric power at the doorstep of practically everyone. The first alternating current system in America using transformers was put in operation in Massachusetts in 1886.¹ This transformer was wound for 500 volts primary and 100 volts secondary. The length of the first transmission line was about 4000 feet. Transmission line voltages have steadily risen since that early beginning in Massachusetts to a present-day voltage of 365,000 volts, and their lengths have increased from a few thousand feet to hundreds of miles. Furthermore, the utility companies are presently experimenting with transmission voltages up to 500,000 volts.

1-02 Radio Interference Concern. Radio interference has been with us ever since the invention of the radio, but it is only comparatively recently that it has been receiving intensive study by engineers. The first receiver, having few tubes and poor sensitivity, would not pick up interference from any great distance. Operators were hindered at times by interference, but the broadcast listeners regarded the radio noises in a very tolerant manner because of the novelty of the entire radio idea. However, the novelty rapidly wore off and demands were made for the elimination of all interference. The problem of radio interference has grown at such a rate, that adequate consideration and development work have been impossible.

Electric distribution and transmission equipment of the power lines was originally one of the principal causes of radio interference. Loose connections at cutouts, taps and terminals, and arcing at insulators and to ground, were the principal cases encountered. Tests, inspections, laboratory research, design changes, and maintenance have removed many of these sources, but cases of loose and corroded connections and faulty equipment still occur and require investigation. However, investigation on transmission lines has now been largely reduced

to locating individual deficiencies.

During the same period, development and increase in use of electrical appliances paralleled radio development. Along with lights, there came into the same homes with radio receivers, one or more of the new appliances - electric refrigerators, mixers, vacuum cleaners, oil igniters, stokers on furnaces, air conditioning, electric razor, etc. All these devices employ motors, thermostats or control contactors, etc., which may contribute to radio frequency disturbances. High-frequency equipment, such as X-ray and therapeutic apparatus, flashing neon signs, electric precipitators and other industrial devices may also contribute to radio-frequency disturbances. In many cases, interference from these sources has been eliminated or confined to the same building or room, but in other cases, the disturbance may be severe enough to carry over electric service lines which are common to several buildings. In particularly severe cases, the interference has been known to spread through space and over distribution and transmission circuits and cause interference over an area of several miles in radius.

1-03 Electric Transmission Equipment. The increase in transmission line voltages, greater transmission distances, and increased radio use has necessitated improvement of transmission line insulators and hardware. This required improved materials and design with higher insulating properties as well as increased mechanical strength. The hardware, also, was required to have added mechanical strength. In addition, all of these items required added investigation with regard to the reduction of generation and propagation of radio interference. The increased use of electrical appliances also required that these appliances be improved with regard to causing radio interference. Of course, a portion of the responsibility for the elimination of radio interference fell on the radio manufacturers, themselves. Thus, in the interest of reducing radio interference, American Standards Association Committee on Radio Electrical Co-ordination; and the Joint Co-Ordination Committee on Radio Reception, comprised of The Edison Electric Institute, the National Electrical Manufacturers Association and the Radio Manufacturers Association, representing the various affected parties, were formed. These committees have done much to eliminate radio interference from home appliances, radio receivers as well as overhead transmission lines. The joint responsibility has been realized and much improvement

in manufactured products and power systems has come about because of this realization.

Concurrent with the work of these committees, there have been rules, regulations and laws enacted and enforced by the Federal Communication Commission concerning interference caused by restricted radiation and incidental radiation devices. The FCC² defines restricted radiation devices as "a device in which the generation of radio frequency energy is intentionally incorporated into the design and in which the radio frequency energy is conducted along wires or is radiated, exclusive of transmitters which require licensing under other parts of this chapter and exclusive of devices in which the radio frequency energy is used to produce physical, chemical or biological effects in materials, and which are regulated under provisions of Part 18 of this chapter." Limits of interference have been established at 15 microvolts per meter at 157,000 feet from these apparatus.

f (Kc)

Incidental radiation devices are defined as "devices which radiate radio frequency energy but which are not specifically designed to generate radio frequency energy." Definite limits have not been determined for incidental radiation devices; however, the regulation does state that they must be operated so as not to cause "harmful interference". Both the incidental and restricted radiation devices were prolific sources of radio interference in past years. Present day operating models of these devices have been radio interference suppressed with the result that very few cause interference.

A very prevalent source of radio interference in home appliances was vacuum cleaners, electric mixers, and fluorescent lights. Most present day models of these appliances have been radio interference suppressed.

The power utility industry has also redesigned and constructed their overhead lines with radio interference reduction in mind. Their insistence on "quiet" insulators and hardware plus the EEC-NEMA-RMA's self-imposed restrictions have resulted in the design and manufacture of insulators, hardware, etc., with improved radio interference characteristics.

Thus, as electronic instruments become more prevalent in home, industry and military services, more emphasis is extended to radio interference reduction.

The possibility of reducing or eliminating the radio interference in the design of all apparatus is being studied by a large number of manufacturers. All products cannot be economically designed to be interference-free but continuous improvements are being made. In certain cases, the consideration of interference reduction has resulted in product improvement.

SECTION 2. GENERAL

2-01 Definition of Radio Interference. Radio Interference, or more properly termed electromagnetic interference, can be defined as any disturbance that introduces a "noise" signal or suppresses the incoming radio signal to such an extent that proper radio reception is unpleasant, overshadowed, or becomes unintelligible.³

The term radio interference encompasses the frequency spectrum of 30 cycles per second to 1000 megacycles and is not limited to the frequency band of the standard home receiver. Thus, the term electromagnetic interference is deemed more proper in that it implies a broad range of frequencies. However, the generally accepted term is "radio interference" which is used to denote disturbances in this wide band of frequencies.

2-02 Generation of Radio Interference. Overhead transmission lines are a common source of radio interference. Any of the individual components of the line, such as the conductor, may generate interference.

Around a conductor on an overhead line, there is a strong electrostatic field set up by the alternating current flowing through the conductor. The air surrounding an energized conductor or metallic part in the electrostatic field is at all times ionized to a limited extent. "An ion is defined as a charged atom, molecule, or radical whose migration effects the transport of electricity through an electrolyte, or, to a certain extent through a gas. The air contains millions of uncharged molecules in the area around a conductor, but it also contains charged molecules that have lost one or more electrons from their normal quota, thus leaving the molecule with a net positive charge. The electric field intensity produced by applying a voltage to a transmission line acts upon these charged molecules causing forces on them that are proportional to the product of the field intensity or voltage gradient and the net charge on the ion. This force causes acceleration of the ions, which would continue to an infinite value were it not for the collision of these ions with other ions and neutral molecules. The distance traveled by an accelerated ion before collision depends on chance, but the average distance can be calculated and is called the mean free path. The mean-free-path distance is dependent upon a number of variables, such as size of the molecules, temperature, and pressure".

"From the foregoing statements, it is obvious that the velocity obtained by a charged molecule is dependent on a number of factors: (1) charge on the molecule, (2) mass of the molecule, (3) mean-free-path, and (4) the potential gradient or electric field intensity acting on the charged molecule. If all these factors are such that they impart sufficient velocity to the ion, the ion upon striking another molecule will dislodge from this molecule one or more electrons, thus producing more ions. If the potential gradient is high enough to bring about a cumulative effect, the ionization process will continue until a condition exists such that the air becomes a high-resistance conductor and spark discharge or corona appears in the immediate area around the conductor or between adjacent hardware. Whether corona or spark discharge occurs depends upon the distance separating the conductors or conductor and ground³, or between the metallic parts on the overhead line. Only the air in the immediate neighborhood becomes conductive; air farther from the line retains its nonconductive value.

Since ions are charged particles, their motion through air constitutes an electrical current flow from the air into a conductor. A sharp breakdown occurs when the voltage gradient becomes great enough to break through insulation caused by corrosion products or a very small air gap. The sharp breakdown results in current pulses rich in radio frequency harmonics and radio interference is generated.

2-03 Propagation of Radio Interference. Radio

broadcasting stations radiate r.f. energy into space by setting up electric waves at the broadcasting antenna. This transmitted signal will be induced into any receiver antenna within its field. This phenomenon is analogous to the action which occurs in a transformer. The broadcasting antenna can be thought of as the primary, of the transformer, and the receiving antenna as the secondary winding. However, the receiving antenna will have induced into it not only the one desired signal, but also other fields which are present. It is the function of the receiver to select the desired signal at its frequency.

Radio interference is propagated into space in much the same manner as the broadcasted signal from a radio station. It finds its way into the receiver by being present at the same frequency as the desired signal. Interference present in this form is termed "radiated interference".

Interference may also travel along a conductor as radio frequency energy travels through a coaxial cable. Interference propagated in this manner is termed "conducted interference".

Whenever current flows through a conductor, an induction field is set up around the conductor. Interference current flows along the skin of the conductor setting up a field around the conductor. Another conductor in this induction field will have induced into it a voltage proportional to the strength of the field. Interference which finds its way to another conductor in this manner is termed "induced interference".

Thus, interference is propagated in three ways: (1) by radiation, (2) by conduction, and (3) by induction. Radio interference may be propagated by any one of these means or by various combinations of them.

2-04 Frequency spectrum of radio interference.

Whenever a broadcasting station transmits a signal, that signal is usually at one definite frequency. However, this is not the usual case with interference. A radio interference generator transmits its "signal" over a wide band of frequencies. The Phase III report of Contract NOy-88454^{4,5} reported interference measured throughout the frequency spectrum of 30 cycles per second to 25 megacycles from 41.6 Kv overhead transmission lines. Published literature reports interference from overhead lines within this same frequency spectrum and higher frequencies. The higher frequency interference was not inherent to overhead lines, but was generated by defective components on the overhead line. The frequency spectrum of radio interference from overhead transmission lines is usually from 30 cycles per second to 25 megacycles. However in specific instances, interference up to 1000 megacycles has been reported.

2-05 Usual Causes of Radio Interference on Transmission Lines.

Radio interference may be caused by any sudden change in potential which may accompany surges, by sparks, or by any current interrupting devices of an electric circuit. Many of these sources of radio interference on power systems may not immediately cause power failure. However, a high order of interference is usually an indication of defective components which may subsequently develop into a line fault and service outage.

Electrostatic discharges may occur wherever the potential gradient between two conducting mediums exceeds the dielectric strength of the air or insulating material between them. This may occur between conductors and insulator pins, between pieces of pole line hardware, etc., which are in the electrostatic field of the system. Considerable radio interference may be caused by sparking between corroded metal parts along the overhead line. A large potential difference may build up between two metal crossarm braces which are not thoroughly bonded. Corrosion products between the two braces may "break" the initial bond. A spark would occur at this point and cause interference which would travel many miles along the line.

Loose hardware is a very prevalent source of radio interference. Two metal parts not securely bonded together, with a small air gap between them is a perfect spark gap generator. Loose hardware, loose tie wire and other loose mechanical bonds along the transmission line are usually due to the constant vibration due to wind, rain and other atmospheric conditions.

Much of the radio interference generated on an overhead line is due to small spark gaps inadvertently built into the line.

SECTION 3. REASONS FOR CONSIDERATION OF INTERFERENCE REDUCTION

3-01 General. The degree of annoyance of radio interference is dependent on the signal-to-noise ratio. A high interference level or low signal-to-noise ratio lowers the quality of reception of a receiver from a transmitter of a given power. Any reduction of the interference level or increase in signal-to-noise ratio raises the useful sensitivity of the receiver towards an absolute limit which depends only on its design.

The signal-to-noise ratio required for various qualities of service are, approximately, as follows:³

| | |
|-------------|---------|
| Excellent | 40 db/1 |
| Good | 30 db/1 |
| Fair | 25 db/1 |
| Intolerable | 10 db/1 |

The generally accepted signal-to-noise ratio of 30 decibels to 1^{6.7} is generally accepted as the ratio which can be practically maintained. This ratio will render good quality reception and at the same time will be economically feasible.

It should be noted that in some instances and under certain conditions signal-to-noise ratios as high as 30 or 35 db/1 have provided poor reception. The ratios stated above are intended as a guide rather than an absolute assurance of good quality reception.

3-02 Improved Reception. Whenever the receiver reception is increased because of a decrease in interference level, the effect is the same as increasing the power of the transmitter. Thus decreasing the interference level and maintaining the quality of reception, allows the use of a lower power transmitter thereby facilitating the use of lighter weight and more mobile equipment. This is obviously very advantageous to military movements, since portability and quality of reception are very important.

In addition to the above mentioned advantages, there is the added advantage of being able to receive stations formerly blanked out by radio interference. This effectively increases the distance of the transmitter.

3-03 Proper Operation of Electronic Mechanisms.

There are, also, other electronically operated equipment which are adversely affected by radio interference. Radio interference can cause malfunction of the sensitive parts of many electronic mechanisms. Equipment utilizing sensitive relays may be affected by radio interference in that this r.f. interference energy would "trip" a relay at an inopportune time.

SECTION 4. MEANS OF IMPROVING COMMUNICATION RECEPTION.

4-01 General. The improvement of radio reception may be made by either reducing the intensity of the radio interference reaching the receiver or increasing the signal strength at the receiver. However, there are practical limits to both the minimum radio interference level and the maximum broadcast signal strength that can be obtained.

4-02 Reduction of Interference. The most practical solution to the problem of improved communication reception is to reduce the intensity of the radio interference to the economically practical minimum. Then the intensity of the transmitted signal could be altered to give a signal-to-noise ratio which would permit the desired reception. However, Phase I of this Contract revealed that no reasonable limit of interference for overhead lines was available. Therefore, Phase II of this Contract was initiated to gather field data of interference present on properly operating and well-maintained transmission lines. Phase III then correlated and established a reasonable level of radio interference from data gathered and literature available. Thus, a reasonable level of radio interference has been established and may be used as a yardstick for determining the radio interference quality of a transmission line. The radio interference, now, may be reduced to the economically practical minimum level corresponding to the limit established by Phase III. Thus, the intensity of the transmitted signal may be altered to give a signal-to-noise ratio which will allow good reception.

SECTION 5. SOURCES OF RADIO INTERFERENCE ON SUBTRANSMISSION LINES.

5-01 Definition of Subtransmission Line. Subtransmission lines are those overhead lines delivering relatively high voltages over short distances. The subtransmission line voltages are stepped down to supply voltage to distribution systems. Subtransmission line voltages range from 12 Kv to 69 Kv depending on the distance of transmission and power requirements at distribution points.

Subtransmission lines throughout this report will be referred to as transmission lines, i.e. lines transmitting voltages of between 12 Kv and 69 Kv.

5-02 Insulators. An insulator, in general, is an appliance which is used to insulate a conductor from earth, or from another conductor, and frequently also serving to support the conductor. Overhead power line conductors are carried on porcelain insulators which are mounted on the crossarm of the pole. An insulator can be considered as the dielectric medium of a capacitor and the line and pin as the capacitor plates. The charging current taken by a capacitor is controlled by three variables: voltage, capacitance, and frequency. For transmission lines, the voltage and frequency become constant; and, for a particular line, the capacitance is also a constant.

The charging current of the insulator would flow freely into the insulator if the electrical contact were perfect. However, as the result of poor contact, resistance to the flow of current is encountered at the line connection and tie wire. This resistance causes the air at the point of contact to become overstressed and ionization to occur. Ionization of the air occurs because its dielectric strength is several times less than the dielectric strength of the insulator. The ionization of the air will manifest itself at three possible points on an insulator: (1) at the point of contact of the line-wire, tie wire and the insulator head (2) between the pin or thimble and the insulator body, and (3) between the individual shells of a multi-shell insulator.

The ionization of the air will present itself on insulators concurrent with electromagnetic interference in two forms: corona and brush discharge. Brush discharge is a form of corona in a more advanced or agitated state. Corona will produce a low audible hissing sound in a radio receiver which may or may not be objectionable; whereas, brush discharge produces a sharp crackling noise that is definitely objectionable.

Electromagnetic interference is also initiated by particles of dirt or dust accumulating on the insulators, particularly in the presence of a high electrostatic field. Dirty insulators will produce as much as 50 percent more interference than the same insulators when clean.

5-03 Tie Wire. Sharp points are very prevalent sources of radio interference because of the overstressed condition of the air which occurs at these points.^{9,10} Tie wire ends can have sharp points which would cause the air surrounding the tie wire ends to be stressed by a greater voltage per square centimeter than any other point on the tie wire. Thus, this excess voltage gradient causes ionization of the air which results in radio interference.

Other point sources of interference at the tie wire are poor contact between tie wire and the conductor and between the tie wire and insulator. An overstressed condition and subsequent ionization of the air is the principal cause of interference at these described points.

5-04 Conductors.

(a). Conductor. In itself, the conductor is not a prevalent source of interference at lower transmission voltages. The specific points of interference generation along a conductor are sharp points which may exist due to a mutilated strand, considerable dirt or dust accumulating on the conductor, or an overhanging wire. The conductor size should be selected so that it will operate at a voltage below the corona limit. If the corona limit is exceeded it will have an overstressed layer of air around it. This overstressed layer of air will cause a hissing sound in the communication receiver.

(b) Spacing. If the spacing of the conductors is such that due to weather condition such as wind, ice, etc., they become very close to each other, the surrounding air will be stressed by a large voltage gradient. Thus, current pulses are set up and consequent radio interference. This situation is not likely to occur but much the same situation is present on many lines. The conductor is close to ground wires feeding down the pole or guy wires anchoring the pole. These situations are inadvertently built into the line. Current surges as a result of these situations are not large enough to cause power failures to occur on the line but are sufficient to cause radio interference.

(c) Splices. Poor contact in a splice will cause sparking and radio interference. Poor contact is not the only prerequisite for sparking in the splice. Connecting two dissimilar metals together at the splice will cause corrosion. Corrosion products will form, offering a high resistance path for current flow. A voltage gradient will become evident when sparking or corona occurs at the splice. The described condition will cause radio interference.

5-05 Poles and Crossarms. Crossarms are installed on transmission line poles to support the insulator and conductors. On wood pole transmission lines these crossarms are generally made of wood also. However, in some instances these crossarms are made of conducting material such as steel. The conducting crossarm, because of its location and physical dimensions, will become an effective antenna. This antenna will radiate any radio frequency signal present. These radio frequency signals include the undesired electromagnetic interference present along the transmission line. The length of the crossarm will determine the frequency at which it will become a "resonant dipole." Since radio interference is present over a wide range of frequencies, the probability of the crossarm acting as an antenna is very great.¹¹

In addition to the conducting crossarm being an excellent transmitter of interference, it may also become a source of undesired interference. Potential sources of interference generation along a metal crossarm are improper bonding of crossarm and hardware, loss of bonding between crossarm and hardware due to formation of corrosion products and sharp points on the crossarm in the presence of the strong electrostatic field.

Metal crossarms or wooden crossarms may be supported by metal braces. Difficulties encountered with metal braces are similar to those encountered with metal crossarms. However, the probability of poor bonding, loss of bonding due to the formation of corrosion products and sharp points is greater with the use of metal crossarm braces. All of these conditions will cause radio interference.

5-06 Hardware. Numerous nuts, bolts, washers, and other metal components are used in the construction of overhead transmission lines to secure crossarms, braces, guyes, insulators, etc. These metal components are located in the strong electrostatic field which surrounds the conductors. As a result of their location, a voltage will be induced in them. The amount of induced voltage will depend on the position of the metal component

in the induction field. The induced voltage in metal components placed too close together tends to equalize. This equalization will be in the form of a spark discharge between the two components. Since a spark is a current surge rich in harmonics of radio frequency, it will cause interference. This is illustrated in Figure 1b.

5-07 Guy Wires. The placement of guy wires along a transmission line is necessitated by stresses other than those paralleling the line. Corner poles, or poles at which the line angles away from its original straight line path, usually require additional strength from guy wires. The placement of the guy wire determines if it will be an interference cause. Since it is in an electrostatic field a voltage will be induced into it. Thus if the guy wire or guy wire support (see Figures 1a, c and d) should brush against or come close to another conducting medium, a spark gap will be set up which will cause radio interference. An illustrative case reported in the literature,¹² cites "a power line dead-end guy wire which had a broken strand projecting and intermittently touching a side guy." The interference generated due to this condition caused annoying disturbance to standard broadcast reception two miles away. Similar interference is possible if the guy wire brushes against wet shrubbery or if the guy wire bracket is placed too proximate to other metal components on the line.

5-08 Ground Wires. Ground wires over the conductors on overhead transmission lines are finding favor in the power utility industry as lightning protection for the line. The ground wire is brought to ground rods either at every pole or some predetermined number of alternate poles. Points of interference generation due to the ground wire will be caused by locating the ground wire too close to the conductors when it is brought down the pole to ground, loose contact of the ground wire at the clamp, close proximity to hardware, or a very high resistance contact between the ground wire and rod or between the ground rod and earth.

The introduction of the ground wire over the conductors on transmission lines produces little change in the interference radiation field transversely to the line, but increases the interference directly under the conductors by about 25 percent. Since this increased field intensity under the conductors was not exhibited beyond a vertical line drawn through the conductors to earth, it can be assumed that the ground wire has no significance in the reduction of electromagnetic interference.³

5-09 Switches. Disconnect switches are used to open and close circuits along the route or loop of the transmission line. They must be designed to carry their rated current continuously without overheating and must have clearances and insulation for the normal voltage of the circuit. These switches are usually mounted atop the pole at strategic points along the line. Areas of possible interference generation on these switches are points of poor contact, corroded contact points, or misalignment of the switch arm.

Components of the switches are mounted on insulators which are in turn mounted on a metal frame. It is very possible for the metal frame to have sharp points, or unbonded or corroded points causing overstressed air, or sparking and subsequently causing radio interference.

Mounting of the metal frame too close to other hardware on the pole will also precipitate radio interference because of small spark gaps.

Insulators on pole top switches become sources of interference if they are not installed tightly or for any of the reasons given in Section 5-02.

5-10 Lightning Arresters. A valve type lightning arrester is composed, basically, of a resistance element in series with a spark gap. It is connected between line and ground, and in parallel with equipment to be protected. When a transient voltage of damaging magnitude, of system or natural origin, appears at the arrester terminals, this voltage must be diverted through the arrester to ground. The action is initiated by sparkover of the series gap. The transient current must then flow through the resistance to ground.¹³

The enclosure containing the sparkgap and resistance circuit is a porcelain housing. This assembly is installed along the line very close to the equipment which it is to protect.

Multiporcelain unit lightning arresters may have an interference generator set up between the porcelain units. This action is similar to the overstressed layer of air in the pin hole of pin type insulators.

In addition to the porcelain housing of the lightning arresters, the spark gap of the arrester could become carbonized sufficiently to allow corona formation within the arrester. This situation

will cause interference of a high order over a large area. Defects in the porcelain, in particular hair line cracks, will cause radio interference of a high order.

5-11 Pole Line Apparatus. Many of the sources of radio interference due to line apparatus are present because of the close spacing of this apparatus to other metal components on the line. Distribution transformers, if mounted on the transmission line pole, could inadvertently be installed close to a guy wire bolt or crossarm. Other sources of interference which may be caused by the transformer case would be loose bolts, washers or panels. Other apparatus such as pole line capacitors, taps, etc. will generate interference similarly if closely spaced or contain any loose connections.

Apparatus bushings may also be a source of radio interference if they are not tightly connected with good electrical contact between all adjoining parts.

5-12 Substations. The substation or switching station is the main point of power distribution. The function of the substation is to step down higher voltages, switch from one circuit to another, fuse circuits, meter power, regulate voltage, etc. Thus, within its confines, the substation contains switches, transformers, switchgear, relays, voltage regulators, bushings, insulators, insulating liquid and metering circuits.

Loose contacts, improper splices, defective bonding and defective porcelain will all contribute to the generation of radio interference for reasons previously discussed. These deficiencies are common to all components in the substation.

Interference generated by switches and switchgear will contribute to radio interference due to corroded contacts, improper alignment of contact blades, or loose contact. Each of these items will cause interference by means of sparkgaps. Transformers will generate interference mostly because of loose contacts or poor bonds on the case of the transformer or defects at the bushings.

Corrosion products between metal parts will cause these metal parts to become unbonded. Should a potential difference exist between the metal parts, the corrosion products will become overstressed to a point where they become high resistance conductors. This situation will lead to a spark gap generator and radio interference.

Interference caused by bushings is due to small cracks which are the result of the shrinkage of the inelastic filling compound. The topcap assembly of the bushing has a thin cork that eventually loses its elasticity and is subject to cracking during rain, snow, or similar weather conditions which cool the bushing rapidly and contract the metal parts. Moisture drawn into the crack in the compound, formed by the sudden contraction of the metal, follows the void to the lowest point, the mounting flange. In time, the moisture forms a conducting path for the current between the cap and the mounting flange.¹⁴ This moisture causes either intense ionization of the air or corona formation. Either will appear concurrent with a high intensity of radio interference.

Other points of interference generation at the bushing are dirty or corroded connections, chips or cracks in the porcelain, leakage of filling, loose fitting ground strap, excessive accumulation of carbon on porcelain or in the oil, or moisture in oil.

Interference caused by relays would most likely be due to "frying-points". However, this situation would be remedied most rapidly since it would interfere with service.

5-13 Sources of Interference Due to Corrosion. The rate of corrosion on insulator and conductor hardware depends not only on atmospheric conditions and kinds of material, but also on electrostatic overstress. Atmospheric conditions vary widely and are of importance in determining the nature of corrosion. An excess of oxygen at the metal surface and an electrolyte are necessary to promote the corrosion. Airborne impurities, particularly oxides of sulphur and salts, will accelerate the corrosion action. Other impurities may serve as a blanket on which moisture may collect to form an electrolyte. Light rain or mist will supply the moisture for the electrolyte and heavy rains will often times wash away the contamination and decrease the rate of corrosion.¹⁵

Tightly adherent products of corrosion may tend to stifle the rate of corrosion, whereas, loose flaky corrosion products will tend to hold the moisture in contact with the metal and accelerate the rate of corrosion.

Leakage currents will flow through an electrolyte on the surface of an insulator causing differential voltages which may develop great enough potentials to cause a breakdown of the air. A discharge may occur at points of high voltage gradients. The ozone

developed by the electrical discharge will accelerate the corrosion of the metal. Electrical discharges will cause a hissing sound in the communication receiver.

5-14 Sources of Interference Due to Contamination.

Paragraph 5-02 has mentioned the fact that dirt or dust particles can cause interference to be generated. This "natural" formation on an insulator can occur at almost any location. However, there is another form of "dirt" on the insulator which is referred to as contamination. Contamination is the crust formation, on the insulator, of chemicals in the air which are peculiar to certain locations. Industrial areas have air pollution. The chemicals which cause this pollution may gather on the insulators. Sea side locations have heavily laden salt air and salt will settle on the insulators. The presence of these chemicals alone do not cause interference. However, these chemicals have the property of absorbing and retaining moisture. When the moisture content of the crust on the insulator is great, it will reduce the leakage distance and allow leakage currents to flow. These leakage currents will generate radio frequency energy in the form of interference.³

Another form of film which may be classified as contamination in a sense, is fog. Fog will precipitate moisture on the surface of the insulator. If the insulator is not uniformly wetted, local hot spots will form on the surface of the insulator. A hot spot could initiate spark discharges and precipitate radio interference from the line.

5-15 Incidence and Nature of Transmission Line Interference. The Canadian Department of Transport, Telecommunication Branch, has made extensive studies of radio interference in the process of enforcing Law B.S. 800. They have recently began a tabulation of the type and number of radio interference sources reported throughout all of Canada. This tabulation, which covers a period of approximately one year, April 1956 to March 1957 reveals that power and transmission line sources constitute 37 percent of all radio interference sources reported.

The breakdown of interference sources from transmission lines of 10 Kv to 90 Kv is as given on the following page.

| <u>TYPE OF COMPONENT CAUSING INTERFERENCE</u> | <u>PERCENT TOTAL</u> |
|---|----------------------|
| 1. Primary (transformer) cutouts. | .21 |
| 2. Lightning Arresters. | .29 |
| 3. Transformers (broken bushings). | .14 |
| 4. Street light fixtures. | .07 |
| 5. Hot line clamps (loose). | 1.00 |
| 6. Other loose series (current-carrying) connections, including ground wire circuits. | 1.42 |
| 7. Defective insulators. | 17.78 |
| 8. Imperfect contact between hardware of suspension insulator units. | 3.84 |
| 9. Loose tie wires. | 39.69 |
| 10. Other imperfect contact with, or between, non-current-carrying metal parts (guys, pins, bolts, etc.). | 2.58 |
| 11. Trees touching conductors. | .14 |
| 12. Normal line fry. | .85 |
| 13. Miscellaneous. | 1.99 |
| TOTAL Interference Sources (April 1956 to March 1957) | 100.00 |

The fact that power and transmission line sources constitute 37 percent of all radio interference sources points out the need for interference suppression of transmission lines. This report indicates that approximately 33 percent to 50 percent of the power and transmission line sources were from the voltage class covered in this report. Thus, a substantial portion of radio interference is generated from transmission lines and should be eliminated in the initial step toward complete suppression of all interference sources.

Loose tie wires constitute approximately 40 percent of the transmission line interference sources and is the largest single culprit. Nearly 18 percent of the sources reported were defective insulators. The other sources listed, although individually constituting a small part of the total, are never the less significant and must be carefully guarded against.

SECTION 6. RECOMMENDED CONSTRUCTION PRACTICES TO REDUCE RADIO INTERFERENCE

6-01 General. Good engineering and construction practices can eliminate much of the radio interference generated on an overhead line. This section describes remedial measures to eliminate the interference generating points stated in section 5. Complete elimination of radio interference generated on an overhead line is an "approachable but unattainable goal".³ Economics, equipment available, and the necessity of complete elimination dictate that this complete elimination is not presently possible.

Construction practices are recommended in this section, which will reduce the number of inadvertently installed interference generators on the line. All equipment on the line and in the substation, discussed and recommended in this section, should conform to NEMA and ASA standards. Applicable publications are outlined in Section 10 of this report.

6-02 Insulators. Numerous systems have been devised to eliminate corona formation and minute sparking at the crown of pin type insulators. Corona formation and small spark gaps are to be avoided since they are interference generators. Some of the numerous treatment of insulator systems which were tried on pin type insulators are the application of a metal cap cemented to the head, the use of metal applied over the top central portion beyond the tie wire groove, the use of an iridescent coating over the head, filling the grooves with a conducting asphalt compound, and the use of a head having the top impregnated with a copper oxide glaze.^{17, 18}

Of the many systems devised, the copper oxide glaze has been by far the most successful. The copper oxide glaze is applied in the factory during manufacture. The advantage of the copper oxide glaze is that it is not a superficial coating on the insulator but an integral part of the insulator crown. Thus, it is not subject to cracking or peeling.

The use of asphalt emulsion applied to the tie wire groove of the pin type insulator has been fairly successful. This emulsion is applied to the insulator in the field. The asphalt emulsion is a conducting medium, bonding together the conductor tie wire, and crown of the pin insulator. A great disadvantage

in the use of asphalt emulsion is the extreme care which must be taken to assure proper field application. F. O. McMillan ¹⁹ describes the care that must be taken during the application of the asphalt emulsion and cites the disadvantages of this system. The coating must be evenly applied over the tie wire, conductor, and tie wire groove. This system should be employed only as a stop gap measure to reduce the radio interference since it is not a permanent remedy.

Rather than proceed with treating pin type insulators to reduce areas of overstress, the insulator industry has designed an insulator, the post type, which bypasses the shortcomings of the multi-procelain insulators. Post type insulators are finding favor in the power utility industry. The post insulator has a very low capacitance which accordingly requires a lower charging current than pin type insulators. The post insulators are not subject to a high order of interference either upon proper installation or after a number of years service.

Mechanical strength is another advantage of these insulators. Since hairline cracks are to be avoided in the insulator porcelain, an insulator with good mechanical strength is advantageous. The post type insulator is mechanically stronger and more convenient to handle and install than the pin type insulator.

Post type insulators are shown on Figure 2. The side groove line tie, top groove line tie, and the clamp top line post insulators are shown. The conductor is attached to the side groove and top groove insulators by means of a tie wire. The clamp top post insulator utilizes a clamp to attach the conductor to the insulator. Assuming proper tie wire connection of the conductor to the insulator, the entire assembly is electrically bonded. The spaces between porcelain which exist on pin type insulators are not present with the post type insulator design.

Pin type insulators have large pin holes for the mounting of the insulator. This point has been an historical source of interference. Many systems have been devised to eliminate spark gaps which generate interference in the pin hole. Zinc thimbles, metal glazes and asphalt emulsions have all been partially successful in eliminating poor contact at the pin hole. However, with the post type insulators, this spark gap generator is not predominantly present. Post insulators utilize metal stud bolts which ensure good electrical bonding between the insulator and the mounting bolt. Thus, another point of interference generation inherent to pin insulators has been eliminated in the post type insulator.

The clamp top post line insulator is preferred for the connection of the conductor to the insulator since positive electrical contact is obtained and preserved. Post clamp top insulators are manufactured for use on transmission lines voltages of 23 Kv or greater.

Another type of insulator employed in the construction of higher voltage subtransmission lines is the suspension type insulator. In order to have a "quiet" suspension insulator string, certain requirements must be met. Each insulator along the subtransmission line must be weight loaded. Contact between insulators must be positive. Metallic material should be galvanized to protect the metals from corrosion.

Most important in the use of string insulators is the fact that each string must be under tension in the minimum amount of 340 lbs.⁶

Throughout the discussion of insulators mention has not been made of the proper insulation level for the subtransmission line. The judgment of the designing engineer dictates the proper level of insulation. The engineer's decision is based on the voltage level of the line, physical location of line, past experience, requirements of the National Electric Safety Code and the practice of the particular utility.

6-03 Tie Wires. Tie wires cause interference due to improper and unknowingly faulty installation procedures. Tie wire ends should be rounded or cut off square to avoid sharp ends. The size of the tie wire should be such that it will fit the insulator groove to secure good contact. When installed, the tie wire should make good contact with the conductor, and the end of the tie wire should be looped, touching the conductor, and be as far from the insulator as is practical. Figure 3 presents one approved method of installing the tie wire.

Aside from the radio interference consideration, this method presents an easy "hot stick" installation of the tie wire, which is an additional savings of line shutdown which may be avoided.

The study conducted by the Canadian Department of Transport points out that loose tie wires cause 40% of all interference along the line. The importance of obtaining a secure tie wire

connection should not be overlooked. The use of the clamp top insulator is strongly recommended. The clamp top insulator provides a more assured connection of the conductor to the insulator.

6-04 Conductors.

a. Diameter. Increasing the conductor diameter is a generally accepted method of raising the corona threshold voltage and thereby reducing the radio interference caused by the conductor. If all other noise generators on the line were eliminated, then interference becomes a direct function of conductor diameter. However, the diameter of the conductor is controlled by the power to be transmitted and also by economy. Eliminating all other sources of interference is not practical, thus, we come to the practical standpoint. The conductor diameter should be such that it will carry the intended power, and is an economically feasible size conductor. Rorden²⁰ maintains that conductors used on present day transmission lines at voltages under consideration in this report are interference free and acceptable from an interference standpoint. Present day conductors are designed to transmit the desired power at a low power loss. As the line voltage is increased the line design is controlled by the conductor diameter as a function of radio interference generation rather than by conductor diameter as a function of power to be transmitted.

b. Conductor spacing. Experiments conducted by Rorden²⁰ and Slemon²¹ indicate that as the distance between conductors in a three phase single circuit system is decreased, the radio interference between the conductors is increased. In this same experiment, it was determined that the radiated interference transverse to the conductor was decreased as the conductor spacing decreased. Sterba and Feldman²² have stated that the amount of energy radiated is directly proportional to the square of the distance between the conductors. Theoretically, as the distance between the conductors is decreased, the amount of interference radiated approaches zero. It is not practically possible to closely space the conductors on overhead, three phase systems. In general, the spacing of the conductors is a compromise between corona losses, lightning surges, economy, climbing space, etc. Thus, the spacing of the conductors should be as close as the above factors permit.

c. Splices. Secure contact must be obtained at the conductor splice to ensure that radio interference is not generated at that point. Pressure sleeves or automatic splices should be used to connect together conductors of similar metals. The splice should never be made by twisting the conductors together. Always use the special connectors designed and manufactured for the purpose if dissimilar metals are to be spliced together.

6-05 Poles and Crossarms. Crossarm material on wooden poles can be either wood or metal. However, metal crossarms are looked upon with disfavor from a radio interference standpoint. Metal crossarms form a resonant dipole for some frequency in the spectrum. The frequency is dependent on the length of the crossarm. The metal crossarm then becomes a radiating antenna for the frequency to which it is accidentally tuned. Thus, any interference present on the line at the frequency to which the crossarm is accidentally tuned will be efficiently radiated. In addition, other frequencies will be radiated somewhat less efficiently. For this reason, metal crossarms should be avoided in the construction of overhead lines utilizing wooden poles.

Wooden crossarms on wooden poles are recommended in the construction of overhead lines.

6-06 Hardware. As described in section 5, the main sources of interference along a transmission line are points of corona formation and spark gaps. Hardware on the crossarm or pole which is closely spaced can cause corona or spark gaps between them with resulting radio interference.

Bolt heads, washers, staples, and nuts on the overhead line pole should be spaced at least two inches apart. Washers which have a square or rectangular configuration should be placed with a side parallel to other metal washers or metallic parts, along the crossarm or pole to insure greatest distance and avoid points towards another metal object as shown in Figure 4b.

Sharp projections on all metal parts should be avoided. Loose hardware, especially poor contact between washers and bolts will cause interference because of poor contact, causing intermittent spark discharges. Lock washers should be used on all nut-bolt assemblies. If further assurance of tight hardware is desired, a lock nut should be used.²³ A spring washer has

been successfully employed to assure tight hardware. The spring washers are used where excessive shrinkage of wood is likely to occur. No lock nuts need be used as spring washers form an effective lock. The spring washer is used under the nut in the same manner as the ordinary washer.²⁴

Static proof hardware is designed to eliminate spark discharges between the bolt and washer. This type of hardware employs a bolt and washer formed into one piece and a nut and washer one piece assembly.

MF lock nuts form a solid unit with the bolt and do not ordinarily loosen regardless of the amount of vibration to which they are subjected. However, even though they are not loosened by vibration, they can easily be removed with any standard wrench.

In order to avoid interference generated at the hardware loose conditions must be avoided. For this reason, static proof hardware is recommended. The static proof bolt washer used in conjunction with a nut and spring washer, or with an MF lock nut should be used.

6-07 Guy Wire. Guy wires are usually in the electrostatic field of the conductors. Since they are in this field they will have a voltage induced in them. The proximity of guy wires to other conducting objects along the transmission line will present an opportunity for intermittent spark discharges. Under such conditions radio interference will commence. Therefore, guy wires should be spaced so that they will not either brush or come in contact with other conducting objects.²³ Figures 4 a, c and d describe the placement of the guy wire and guy wire bracket to avoid either contacting or brushing other conducting objects.

Guy wires should be kept taut. This will maintain contact between the guy wire and its mounting bracket and also prevent it from swaying. Guy wires should not brush against trees or shrubbery. These items are conducting mediums of high resistance. A voltage could be induced into the guy wire causing an intermittent spark to the tree or shrubbery.

Each guy wire should have its own guy wire bracket on the pole. Avoid the practice of connecting two guy wires to one guy wire bracket.

6-08 Ground Wire. The ground wire connections are as potential a source of radio interference as the conductor connections. The connection to the ground wire at the pole should be a clamp locking type. When the ground wire is guided down the pole it should remain away from other conductors and hardware.²³ Figure 5 shows one method employed by The Detroit Edison Company to assure proper distances from the conductors and pole line hardware.

The resistance of the ground wire to earth should be below 10 ohms. This will provide a fair r.f. ground. A lower resistance would present too stringent a requirement upon the construction.

Ground wires to ground rods should be covered by a wooden molding with the staples over the molding to maintain a distance between the staples and the ground wire. The ground molding should cover the ground wire from the grade to within three feet of the lowest crossarm supporting the high voltage conductors.

6-09 Switches. The "make" contact on a pole top switch, or loose hardware on the switch, could produce radio interference by setting up a spark gap situation. This situation occurs at the contacts when a positive connection is not obtained or when the contact points have been burned or corroded. Metal parts on the switch which have become loose will produce radio interference.

Pole top switches used on overhead transmission lines should have clean positive contacts. Components of the pole top switch apparatus should be well tightened and bonded together.²⁵

Post type insulators design is recommended as the insulation used in conjunction with the pole top switch.

6-10 Lightning arrestors. The porcelain shell of the lightning arrestors should be similar in configuration to the post type insulator. The design is self cleaning in normal atmospheres and thus prevents minor contaminants from remaining on the porcelain.

The metal to porcelain mounting of the lightning arrestor should be a tight connection to ensure that a spark gap or intermittent sparking will not occur.

Construction of the lightning arrestors should be such that corona formation or sparking will not occur internally.

Radio interference-free lightning arrestors should be specified for all new construction. A lightning arrestor determined to be an interference generator on old construction should be immediately replaced with a radio interference-free type.¹⁰

6-11 Pole Line Apparatus. All apparatus within the electrostatic field of the conductors should be designed, constructed and maintained so as to avoid, as far as is economically feasible, potential gradients which would be sufficient to cause an electrical discharge. The apparatus should not permit electrical discharges at the highest voltage at which the system is intended to operate normally, and under ordinary weather conditions.

6-12 Substation Construction.

a. The substation may act as a transferring medium for the radio interference if certain precautions are not observed. The subtransmission line or power lines could have interference induced into it from higher voltage lines. This interference would travel many miles along the subtransmission line. Figures 6, 6a and 7, 7a show how to exit the subtransmission line from the substation in order to avoid this situation. The underground exit of the line from the substation presents the most satisfactory solution. In this installation, the line leaves at an angle of 90° to the incoming line. The underground portion of the line extends 200 feet at which distance it is away from the possible strong interference field of the higher voltage line.²⁵ The lead sheath of the underground cable should be grounded to zinc ground rods with a resistance to earth of not over 3 ohms. The second solution shown in Figure 7 places the subtransmission line exit at a point farthest away from the higher voltage line and in the same direction. This system reduces the probability of interference being induced into the subtransmission or power line from the transmission line or subtransmission line. The straight distance away from the substation should be 200 feet.

Substations should be located away from areas of possible contamination. If near a spray pond, the substation should be located on the windward side of the pond. Longer transmission lines which result from locations away from contamination may be justifiable in the resultant lower maintenance cost.

b. The case of the transformer in the sub-station should be grounded through a very short, large diameter cable or a strap to provide a good r.f. ground. The resistance of the ground rod to earth should be in the order of 3 ohms as measured with a Megger or Vibraground.

c. Bushings. Lower voltage bushings are usually of the dry type. In the purchase of these bushings, a radio interference free type should be specified. As higher voltages are used, oil filled bushings come into use. Liquid filled bushings are generally characterized by low radio interference voltages. A high interference level, which is not eliminated by cleaning the porcelain, indicates that the liquid level of the bushings and apparatus should be checked.

d. The measurement of the radio interference at the transformer-bushing assembly can be used to determine the quality of the insulation of the assembly. A reading below the NEMA level (described in section 10) is an indication that the bushings are free of any incipient dielectric damage. An interference level "in excess of five times the NEMA level is considered reason for removing the bushing from service".²⁶

e. Fuses with corrosion resistant ferrules should be used. The fuse receptacle should hold the fuse firmly in place. Fuse receptacles which are loose or "sprung" should be immediately replaced.

6-13 Consideration of Corrosive Conditions.

Typical ferrous metals used for insulator and conductor hardware are carbon steel, low alloy steel and malleable iron. The usual procedure is to hot dip galvanize these ferrous metals. In damp atmospheres, the zinc coating develops a surface of white zinc oxide which changes to basic zinc carbonate. In mild climates this acts as an insoluble seal and often halts further corrosion.

In atmospheres contaminated with salts or acid fumes, the basic zinc carbonate decomposes allowing further reaction with the zinc coating. The zinc will protect holidays exposing ferrous metals as large as 1/8" in diameter. Larger areas of exposed ferrous metal will decompose under the chemical attack to form reddish oxides of iron.²⁵

"Brass and bronze alloys are specified for critical parts like cotter pins, and for insulator and conductor hardware, when corrosion resisting, non-magnetic or current-carrying characteristics are especially useful."¹⁵ These alloys form corrosion films of oxides or basic carbonates in mild atmospheres. In more corrosive atmospheres, these oxides and/or basic carbonates are dissolved away somewhat more slowly than those of zinc or ferrous metals.

The use of aluminum alloys is specified in conjunction with the designs employing ACSR cables. The aluminum alloy suspension and strain clamps used with aluminum conductors have been beneficial because of their non-magnetic, corrosion resisting nature.²³ These alloys form an impervious oxide layer which retards further corrosion. Silicon bronze and stainless steel have been used to replace the carbon steel parts of insulators or conductor hardware for extreme industrial or marine exposure. These metals have been employed only in extremely corrosive atmospheres. This solution involves an increase in manufacturing cost and can be justified only where the greater hardware life permits a substantial savings.

Corrosion factors are sometimes a determining factor in the location of a substation or overhead line. Substations should be located on the windward side of a spray pond. A longer transmission line can be justified if it avoids areas of atmospheric contamination thus reducing maintenance costs and radio interference intensity.

The amount or degree of corrosion of metal parts will vary with the concentration and kind of pollution, degree of rainfall, wind direction and velocity, amount of voltage stress and other atmospheric conditions such as humidity and temperature. Thus, the selection of the components on the overhead line should be selected considering the atmospheric conditions of the area.

In general, hot dipped galvanized malleable iron resists atmospheric corrosion more effectively than carbon steels. When malleable iron clamps are used in conjunction with steel bolts and nuts, the steel rusts but the iron remains intact. Many utility companies find it economical to replace the steel parts and continue such clamps in service.

For suspension insulators with steel pins and malleable iron caps, the limiting part is usually the steel pin. The steel pin should equal the corrosion resistance performance of the malleable iron.

With regard to the grounding system used for overhead transmission lines, certain precautions should be observed. Dissimilar metals should never be connected together in an electrolyte. This is extremely important since the rate of corrosion of metals is greatly accelerated by such common practices as connecting steel and copper together where an electrolyte (earth) is present. This may occur where a steel guy wire is connected to the copper ground system. If one of the dissimilar metals is insulated from the electrolyte, accelerated corrosion due to the dissimilar metal couple will halt. Thus, if copper is connected to a steel ground rod, the copper should be insulated from the electrolyte both at the junction and wherever it is in contact with the electrolyte. It is necessary to isolate the copper, in this instance, entirely from the electrolyte.

In some cases the galvanic couple can be broken by installing in the wire an insulator. This insulator will break the DC continuity of the system but not the mechanical strength. This method is especially recommended on guy wires.

Table No. 1 lists the galvanic series of metals in an electrolyte (such as earth). If two metals are connected together in earth, the metal nearest the top of the table will corrode to the metal lower in the table. Thus, if steel were connected to copper underground, the steel would corrode at an accelerated rate. Only metals which are close together on the table should be connected together.²⁷ An example of this would be cast iron and mild steel.

In certain instances it is desired to connect one metal to another in order to sacrifice one to protect the other. This is termed cathodic protection. It is far better to ground lead to zinc ground rods or galvanized steel ground rods than to copper ground rods. Using zinc or galvanized steel as the ground rod performs two functions: (1) the lead sheath is properly grounded; and (2) the lead sheath is under cathodic protection. Should copper ground rods be used, the lead sheath will corrode at an accelerated rate to protect the copper ground rods. Thus, it is safer and more economical to use ground rods which will provide the necessary ground resistance and which will not accelerate corrosion.

TABLE NO. 1

GALVANIC SERIES OF METALS

Corroded End (Anodic, or least noble).

Magnesium

Zinc

Galvanized Steel or Iron

Aluminum 2S

Cadmium

Aluminum 356

Aluminum 195

Mild Steel

Cast Iron

Stainless Steel (18-8) (Active)

Lead-Tin Solders

Lead

Tin

Nickel (Active)

Brass

Copper

Bronze

Nickel (Passive)

Stainless Steel (18-8) (Passive)

Silver

Graphite

Gold

Platinum

Protected End (Cathodic, or most noble)

The recommended practices with regard to corrosion are:

1. Hot dipped galvanized malleable iron, carbon, steel, or low alloy steel should be used for all hardware and metallic parts in normal atmosphere.
2. In corrosive atmospheres, non-corrosive metals which are most corrosion-resistant in the particular atmosphere in question, should be used.
3. Similar metals shall be used in making electrical connections whenever possible.
4. Whenever it is necessary to connect dissimilar metals, in the presence of a continuous electrolyte, one metal must be insulated from the electrolyte by using moisture resistant rubber tape.
5. Use galvanized steel or zinc ground rods and tape the ground wire one foot above ground level to and including the ground rod connection with moisture resistant rubber tape.

6-14 Recommended Practices for Porcelains in Contaminated Areas. In many areas, heavy surface contamination of insulators is caused by salt spray, dust, industrial fumes, concrete dust, etc. This contamination ordinarily is not harmful if heavy rains are frequent enough to keep the insulators washed. However, if light rains or fog are common, the contaminants collect moisture and cause not only radio interference, but also crossarm charring, pole top fires, and insulator flashovers.

The remedy for radio interference caused directly by contamination is dependent upon each particular location and situation. Frequently the remedy may be an increase in the level of the line insulation. The minimum precautions which should be observed in order to minimize radio interference in contamination areas is overinsulation of the line by 33-1/3% using fog type insulators. Further overinsulation may be required in some instances. Since contamination varies with locations, the amounts of overinsulation should be determined with each situation.

In areas of high contamination, the 33 1/3% increase may not eliminate radio interference due to contamination. Under these conditions an insulator washing program should be investigated.

The criteria of a program of washing insulators is dictated by such factors as dry weather or excess contamination. During dry spells, contaminants gather on the insulators and are not washed off by rain. Excessive contaminants gathering on the insulators, which are not washed off by rain, should be washed off by a high pressure stream of water.

The high voltage insulators should be washed by a high pressure stream of water from a firehose on a truck. This operation must be performed only under proper, experienced supervision.¹⁰

"Caution" should be exercised in performing the washing operation. It should not be attempted by anyone except authorized personnel of a power company or persons thoroughly familiar with high voltage equipment. All normal safety precautions must also be observed.

The hose nozzle must be securely grounded for the operator's protection, and the operator should be provided with a well insulated platform on the truck. The time required for each pole is only a few seconds and thus it is not an expensive procedure.

The insulator surface contaminants peculiar to some areas cannot be removed easily by a high-pressure water stream. In this case, silicone materials, such as "Insulcone", are available from the insulator manufacturers for applying to the insulator surfaces. After the silicone is applied to the clean insulator surface, most contaminants will adhere only very lightly and can be easily washed away by a stream of water.

6-15 Radio Frequency (r.f.) Choke Coils. Choke coils present a method of attenuating conducted interference along a desired length of the overhead line. The choke coils are placed in series with each phase of the overhead line. At the lower voltages, r.f. choke coils can easily be installed and can be justified from an economic standpoint. As the voltage increases it becomes somewhat doubtful as to the economic justification of using choke coils as opposed to rebuilding the line. Choke coils for the higher voltage lines become somewhat physically larger due to higher voltage requirements. The larger size of the coils presents installation inconveniences along with higher costs. Before choke coils are considered, the cost of rebuilding the overhead line

as described in this section, should be compared to the cost of installing choke coils. It should be remembered that choke coils do not eliminate the interference conducted on the line, but merely attenuate it. The decision to use choke coils should be based on such factors as:

1. The interference generating line can not be rebuilt economically because of its length, etc.
2. Interference along a section of the line not on the naval establishment can be tolerated but not where it feeds on to the naval establishment.
3. Economic justification, location, and feasibility of installation.

Choke coils are effective in reducing the transmission of radio interference over a range of frequency corresponding roughly to the standard broadcast band, if the coils are properly installed. At higher frequencies, effectiveness is poor because of the inter-turn capacitance of the coils. Choke coils can be designed to reduce interference in other relatively narrow frequency bands, but never to cover all bands with a single coil or set of coils.

It is recommended that choke coils designed for a specific frequency range be used when it is found that serious radio interference occurs only in that specific band.²⁸

Radio frequency choke coils are induction coils placed in series with the power line. The coils are so designed to present a high impedance to radio frequencies and a very low impedance to sixty cycles. Isolation of sections of power lines from radio interference is accomplished by placing these r.f. coils in series, properly spaced along the line, at each end of the section to be isolated.^{18,29,30} "Two of these coils, in series, in each power wire, constitute an attenuation section and reduce the interference level approximately 25 db. (a ratio of 15 to 1)."

"Two sections of attenuation consist of three coils in series, the center coil being larger than the end coils. This arrangement gives approximately 50 db. noise attenuation (a ratio of 300 to 1). More sections can be added if necessary."⁹

R. F. Coils will prevent interference originating outside the naval establishment from entering the naval property on the overhead lines. The coils will not prevent or attenuate interference originating on the isolated section of overhead line on the naval establishment. The previously described precautions, for the prevention of radio interference generation, should be observed within the naval establishment.

Should this system be desired, an interference company, specializing in r.f. choke coils, should be consulted. Extensive investigations are being conducted on the problem of filtering radio interference out of an overhead line by the U. S. Naval Civil Engineering Research and Evaluation Laboratory at Port Hueneme, California. The experience gained by this laboratory in their numerous investigations should be utilized in the consideration of choke coils or filter installations.

6-16 Attenuation by Means of Underground Installations. Another method of preventing radio interference from entering a naval establishment from an outside source is to place the power line underground in cable.²⁵ The capacity of the cable provides a by-pass of low impedance for the radio frequency energy which is drained off to ground, leaving very little radio interference on the line when it is again brought overhead. The underground portion of the line should be at least 100 feet. The lead sheath of underground cable should be securely grounded to zinc ground rods with a resistance to earth of not over 3 ohms.

6-17 Miscellaneous Items. A conductor passing through a tree should have at least three feet clearance to any part of the tree. Trees should be trimmed as required.¹⁴

Should insulated wire be used on any of the overhead lines, certain precautions are necessary to avoid radio interference generation. Before connecting the cable to the insulator remove insulation from the cable. Tie wire should contact only bare conductor. Remove insulation at any point where conductor comes in contact with insulators, or dead ends.²³

All foreign material should be kept off the line. Kite strings and hay wires are prolific radio interference generators and should be removed from the overhead line.²³

6-18 Interference Suppression at the Receiver.
Complete interference suppression is not presently possible. Transmission line interference is a portion of the total interference present. Atmospheric disturbance, over which man has no control, plus interference from man-made objects, all contribute to the overall intensity of interference.

Every effort should be made in the design of the communication receiver to suppress incoming interference. This precaution in the design stage will aid in the apparent reduction of the overall interference.³¹

6-19 Summary of Recommendations. Figures 5, 8, 8A, 9, 10 and 11 present recommended construction practices for overhead transmission lines. These figures show an overall view of the construction. Specific points are listed below.

Insulators

1. Use post type insulators of the proper Kv rating.
2. Clamp-top, post type insulators are preferred.
3. Suspension insulators, when used, shall be weight loaded by 340 lbs. at all times.

Tie Wires

4. If tie wires are used, they shall be installed as shown in figure 3.

Conductors

5. Use the largest diameter conductor that can be economically justified.
6. Space conductors as close together as economy of power loss and safety will permit.
7. Use pressure sleeves or automatic splices for splicing conductors.
8. Use special connectors, designed for the purpose, when splicing conductors of dissimilar metals.

Poles and Crossarms.

9. Use wooden poles.
10. Use wooden crossarms and crossarm braces.

Hardware

11. Use static proof hardware.
12. Use spring washers or MF lock nuts.
13. Space all hardware at least two inches apart.
14. Place square or rectangular washers with a side parallel to adjacent metal parts.

Guy Wires

15. Place guy wire clear of other metal structures along the line and on the pole.
16. Use a guy bracket for each guy wire.
17. Guy wires shall be kept taut at all times.

Ground Wires

18. Place down pole ground wire clear of conductors and all hardware.
19. Use wood molding over ground wire down the pole with staples over the molding and not the wire.
20. Resistance to earth of ground shall not exceed ten ohms.

Pole Top Switches

21. Tighten all pole top switches and switch mounts before installation.
22. Place pole top switch supports at least two inches away from all other unbonded metal on the pole.
23. Round any sharp points on pole top switches.
24. Check "make" contact of all switches to assure that they are clean and provide a positive connection.

Lightning Arrestors

25. Use lightning arrestors of the radio interference free type.

Substations

26. Place the low voltage exit, from a substation, underground and at an angle of 90° minimum to the entering high voltage line for a minimum distance of 200 ft. (see figure 6); or see item 27, Page 39.

27. Exit low voltage line, overhead, at an angle of 180° to the incoming high voltage line (See figure 7).
28. Locate substations away from areas of possible contamination.
29. Transformer cases shall be grounded through a short strap and the resistance to earth shall not exceed three ohms.
30. Use bushings of the radio interference free type.
31. Use fuses with corrosion resisting ferrules, make sure fuse fits tightly in clips.

Contamination

32. Insulators in contaminated areas should exceed normal insulation by 33 1/3% minimum and be of the fog type.
33. Washing of insulators may be necessary in dry climates or areas of high contamination.
34. In areas of heavy contamination, a program of washing the insulators should be initiated.

Radio Frequency (r.f.) Choke Coils

35. R.F. Choke coils may be used to attenuate conducted interference

Underground Attenuation

36. Placing sections of the line underground may also be used to attenuate conducted interference.

Corrosion

37. Hot dipped galvanized malleable iron, carbon steel, or low alloy steel should be used, for all hardware and metallic parts, in normal atmospheres.
38. In corrosive atmospheres, non-corrosive metals, which are most corrosion resistant in the particular atmosphere in question, should be used.
39. Similar metals shall be used, in making an electrical connection, whenever possible.
40. Whenever it is necessary to connect dissimilar metals, in the presence of a continuous electrolyte, one metal must be insulated from the electrolyte by using moisture resistant rubber tape.

41. Use galvanized steel or zinc ground rods and tape the ground wire from one foot above ground level to and including the ground rod connection with moisture resistant rubber tape.

Miscellaneous

42. Trees and shrubbery shall be trimmed to prevent conductors, guy wires or ground wires from touching or brushing against them.
43. Conductors shall have three foot clearance to the nearest tree branch.
44. If insulated cable is used, the insulation shall be stripped off cable at all insulators or dead-ends.
45. Foreign material, such as kite strings, hay wire, etc., shall be removed from the overhead line immediately upon notice.

SECTION 7. DETECTION OF RADIO INTERFERENCE

7-01 General. No definite instructions can be given an investigator to enable him to go directly to the source of interference on a transmission system, and no instrument has yet been designed which will invariably point to the source of interference. There are, however, many instructions which will give indications that will assist the investigator. But, in order to locate the source, the investigator must understand the fundamentals of radio frequency conduction and propagation and be familiar with the electrical system under investigation. The following notes may be helpful.

Weather Conditions Affect Interference Source

Much of the radio interference originating from a transmission line may disappear in wet weather, though sometimes the opposite effect is noted. Sources affected thus, include:

Conductors - Any rain or water on the conductor will lower the threshold voltage of corona and increase the interference level. Drops of water form on the lower or bottom part of the conductor and introduce a region where the air can and will become overstressed, resulting in corona and increased electromagnetic interference.

Loose Tie Wires - The moisture from rain, fog, frost or early morning dew will form a conductor between the tie wire and power line and thus provide a temporary bond, often preventing electrostatic discharge.

Normal "High Tension Fry" - Frequently moisture on top of an insulator will form a conducting surface bringing the entire upper surface of the insulator to a potential equal to that of the line, and thus preventing electrostatic discharge through overstressed air to the surface of the insulator. These electrostatic discharges are heard in the receiver as a high tension fry. This moisture produces an effect similar to that produced by the conducting surface which is applied to silent type insulators. The silent type insulator is, however permanently silent while the untreated insulator becomes noisy again when dry.

Loose Hardware - Wet weather will also reduce much of the interference originating in loose hardware as the moisture will temporarily bond the various parts of the hardware.

A further clue to the location of the interference source is the time required for the interference noise to return after rain. The top of insulators will dry out before the moisture between hardware parts dries.

7-02 Conducted and Radiated Interference. In order to trace radio interference conducted on transmission lines, the investigator should understand some of the characteristics of conduction and radiation. Most interference sources on transmission systems produce radio frequency energy, varying in intensity, at many frequencies. The attenuation of the interfering energy along power lines depends on a number of factors including:

Radio Frequency - The radio energy at low frequency tends to travel many miles along the line. Attenuation along the line at high frequency is much greater. Therefore, it is desirable to use a range of frequency for patrol of transmission lines to determine radio interference sources. The receiver may be tuned to progressively higher frequencies as the source is approached. Care should be taken, however, to avoid misleading results from peaks of interference remote from the source which may be sharper at higher frequencies.

The R. F. Characteristics of the Line - The radio frequency characteristics of the circuit depend upon many factors including the physical spacing of the conductors, its inductance, and the r.f. impedance of the circuit to ground.

7-03 Patrol of the Transmission System. The radio receiver having a rod antenna may be used for determining if radio interference is radiating from a particular transmission line. If the interference is radiating from the line in question, the interference will be higher under the line and will attenuate when the receiver is moved perpendicularly away from the line.

If the interference is not being radiated from the line, the interference level will be lower under the line due to a shielding effect and will increase as the receiver is moved away from the line.

In order to locate the source of radio interference radiating from transmission systems, a patrol of the system is necessary. For this purpose, a portable receiver with rod antenna or a car receiver with whip antenna may be used and an endeavor is first made to find the points of maximum interference radiation at a frequency near one megacycle or at the interference frequency if the interference is at a single frequency. If the interference is at a specific frequency, care must be taken to avoid harmonics which could cause erroneous results. The receiver should be tuned to the lowest frequency at which the interference is transmitted. When performing the operation, it is necessary to consider, and hold as nearly constant as possible, the distance between the line or associated conductors and the receiver.

When patrolling the line with the receiver in the car, care must be taken to observe the distance from the antenna to the nearest wires radiating interference. If the line does not follow the road at a uniform distance, it is desirable to take all readings directly under the line. However, the location of the peaks can usually be made from a vehicle on the road. It will be found that peaks of interference occur when driving under service wires, near ground wires on power lines, transformers, and street lamps, etc. Peaks of interference also occur due to change in the radio frequency characteristics of the line at various locations on the system. These points have frequently misled investigators to locations several miles from the source. It is, therefore, important in the preliminary patrol of the system to cover a wide area, and before spending considerable time at any one peak, the intensity of the various peaks of interference should be compared and subsequent effort concentrated on the most intense peak.

After patrolling the line at a frequency near one megacycle, the receiver should be tuned to higher frequencies, and the frequency may be increased to 25 megacycles. The receiver should be tuned to increasingly high frequencies as the search area is narrowed down, because the interference signal level changes faster with distances at higher frequencies, making it easier to determine the exact location of the source. Exception

is made to this in the case of single frequency interference. In this case the receiver, of necessity, must be kept tuned to the specific frequency of the generated interference.

Occasionally, the intensity of interference immediately adjacent to a fault on a transmission line is less than the intensity at points either side of the source. This may be accounted for by the fact that radio interference, 180° out of phase, is being radiated from the line at each side of the fault and this radiation tends to cancel out, thereby reducing the interference voltage on the receiving antenna.

In order to compare the interference intensity at various peaks, the volume control of the receiver may be adjusted to near threshold of audibility.

The output voltmeter connected to the receiver is an added help in comparing interference intensities.

When it is believed that the maximum radiation has been reached, the actual source may be determined by:

- 1) Visual inspection (binoculars are useful).
- 2) Listening for sound from electric spark.
- 3) Mallet test.
- 4) Shaking wires and tapping apparatus with an insulated stick.
- 5) Switching test.

Before shaking wires it is advisable to conduct tests 1) through 3) thoroughly, as the shaking of the line may temporarily clear the "fault" and make further investigation more difficult.

7-44 Portable Receiver. The first essential for locating radio interference is a portable radio receiver covering the frequency range in which clear reception is required. The Stoddart Test Set PRM-1 is very suitable for these measurements. Although this instrument requires frequent calibration and must be moved about with care, it is the most accurate for making field surveys or patrols. Weighting circuit

made up of appropriate condensers and resistors are used to give an indication of the interference field in terms of "peak", "quasi-peak", or "field intensity" values. The peak value is an approximation of the actual maximum amplitude of individual pulses. The quasi-peak circuit stores up several successive peaks for a short time, and the reading will depend on how fast the peaks occur. The field intensity circuit stores up the impulses for an even longer time and indicates the average value of the interference. The most useful reading for location of the sources of interference is the peak value.

7-05 Mallet Test. Sources in the form of loose connections on a transmission system may be located by striking the pole with a mallet and listening for any change in the intensity or quality of the radio interference from a nearby receiver. By striking the pole with a mallet, all the apparatus on the pole is caused to vibrate and the wire or metal, at the "fault" with vibrate sufficiently to vary the radio interference, and cause a response in the radio receiver. Such "faults" as loose tie wires, loose transformer cut-outs or loose pole line hardware are found by this test. The amount of vibration required to give this response is so small that very often a slight tap with the hand is sufficient. It is very important that the pole not be struck with great force, since this may temporarily clear the "fault" without revealing its cause, and will require duplication of the search at a later date. When the pole is struck, an immediate change is a good indication of hardware noise on the pole being struck, while a delayed change may mean that the vibration has travelled along the line conductors to disturb offending hardware on a neighboring pole. The time required for mechanical vibration to travel from the pole struck to a distant loose connection will sometimes give an indication of the distance of the "fault" from the pole struck. For example, an appreciable delay between striking the pole and hearing or reading the receiver response may indicate the fault to be several spans away.

When a pole is struck in the direction of the power line, the vibration will travel further along the line than when it is struck at right angles. Where lines run at right angles, this may give an indication of the direction of the "fault". A mallet having a rubber face will not mar poles. Rubber from an old tire may be attached to the face of a wooden mallet.

7-06 Shaking wires. The insulated stick is used to gently probe the hardware, ground and bond wires, tie wires, insulators, and so on, while the receiver output is carefully noted. When the offending item is moved slightly, the interference will change or stop, and the cause can be identified.

"Caution" should be exercised in performing the shaking test. It should not be attempted by anyone except authorized personnel of a power company or persons thoroughly familiar with high voltage equipment. All normal safety precautions must also be observed.

7-07 Switching Test. Switching tests are a very satisfactory means of definitely determining the circuit or apparatus on which the radio interference originates, and, in the case of apparatus or appliances, is frequently the most convenient method. Switching tests on transmission systems are usually left as a last resort.

It is usually more satisfactory to determine if the radio interference ceases the instant the switch is opened than to listen for the interference to commence on closing the switch, as the interference may not start the instant the voltage is applied. For this purpose, it is necessary to "kill" the voltage at the suspected source and not merely open the circuit.

In switching tests, great care is necessary to determine whether the interference ceases the instant the switch is opened as it frequently happens that interference from some other source may cease about the time the tests are carried out. If possible, the investigator observing and listening to the interference from the receiver should be in sight of the switch being opened but, where this is not possible, a check on time should be made with watches synchronized within one second.²⁵

SECTION 8. MAINTAINING LOW RADIO INTERFERENCE LEVEL

8-01 General. Maintaining overhead transmission lines in a radio interference-free condition is of extreme importance for several reasons. The main reasons are the necessity for maintaining good communications, accuracy of radio instrumentation, and uninterrupted control of sensitive relays. Occurrence of radio interference originating on the line itself is generally a warning that serious trouble is developing in the power system in the form of defective line components. Investigation should be made of every source of interference in order to forestall a possible power failure. In this respect, interference control may be thought of as preventive maintenance. This control is desirable not only to keep interference to a minimum, but also serves as a beacon light locating defective components which have not progressed to the point of causing a power failure. Power outages are costly and the savings of this one item alone will more than justify the cost of interference control maintenance. Each additional source of interference that develops multiplies the difficulty of locating any other source; therefore, there is no economy in delaying the location and correction of a source of interference in order to handle several "faults" at once. If several interference "faults" are allowed to develop, the addition of unsuppressed equipment to or near the transmission system is likely to go unnoticed, and the control of such equipment will become extremely difficult. Also, to further prevent the development of interference, line crews should be trained to watch for the potential causes of interference.

It is recommended that the transmission system be patrolled at two month intervals and after any power outages or severe electrical storms. A patrol of the system is also recommended immediately after the line has been constructed, rebuilt or after any major repair. This patrol will locate any construction defects which can be repaired immediately so that intense radio interference emission can be avoided. The procedure outlined in Section 7-03 of this report, should be followed in performing these patrolling operations. It is also advisable to have field glasses when making the patrol. The field glasses are used to inspect the points of interference generation. Thus, the exact cause of the interference may be observed from the ground. It is possible that the "fault" generates interference only intermittently. Thus, such things

as charred crossarms, damaged insulators, etc. should be watched for during the patrol. These items should be repaired, even if they are not continuously causing interference, as they are probably causing interference at intermittent intervals.

8-02 Performance of Tests. The cost of interference-measuring instruments is very high and calibration is expensive and time-consuming. Since a full field survey of any particular station is needed only occasionally, approximately once a year, it is generally advisable to have the survey made by a local private contractor. Several firms have the necessary instruments and experienced engineers needed for such surveys, and will furnish their services at reasonable cost. However, the periodic line patrols are of such a nature and the equipment is such that they may be performed by Navy personnel.

SECTION 9. ECONOMICS OF RADIO INTERFERENCE CONTROL

9-01 General. The problem of elimination of electromagnetic interference has been under consideration by electrical and radio engineers for about 45 years. Interference elimination is desirable in that it would result in increased quality of radio reception. Furthermore, radio interference can play a villainous role in causing malfunction of electronic mechanisms. Thus, it can be seen that complete interference elimination would be advantageous. However, complete elimination of electromagnetic interference from transmission lines is an "unattainable goal"; but reducing the interference to an acceptable level is economically attainable.

In order to set the "acceptable level", the magnitude of inherent interference from well designed and maintained transmission lines must be known. From the investigation conducted in Phase II, and information available in the literature, a practical limit of interference from transmission lines, up to 66Kv, was established in Phase III. This is a level which is economically and practically feasible and can be substantiated by field data and current literature.

Phase IV is a study of the procedures and equipment for the suppression and mitigation of electromagnetic interference voltage to acceptable levels. This study includes recommendations on power line components, such as, transmission lines, up to 69Kv and substation equipment. Phase IV concludes that the most practical method of suppression and mitigation, for both new and existing overhead transmission lines is the elimination of the interference sources. The elimination of potential interference sources and a safeguard against the formation of sources includes:

- 1) Proper selection and testing of material.
- 2) Proper construction practices.
- 3) Proper maintenance, including radio patrols.

The control of radio interference from overhead transmission lines is not an expensive operation. In fact, if the benefits derived from this control could properly be evaluated, the savings would greatly exceed any slight increase in cost. The control of interference must be considered in all phases of construction. Consideration in the design involves simply the selection and proper spacing of interference-free type components. The cost of these components does not add substantially to the overall cost of the transmission line.

The consideration of interference control in construction does not vary the cost appreciably. These construction practices will be very similar, if not identical, to the usual construction practices. However, a slightly increased cost will result due to the necessity for a more stringent quality control check. In the maintenance of overhead lines, patrol of the system with radio interference equipment may be in addition to normal patrol procedure. However, some progressive utility companies have initiated this system and found it to serve a dual purpose. Radio interference sources are located but these sources are also defects in the line which are likely to develop into a cause of power outage. Thus, preventive maintenance rather than radio interference control would more properly designate this patrol. Following this logic, interference patrols do not increase maintenance costs but, conversely, reduce them.

9-02 Future Construction. Installation of radio interference free hardware and insulators for new construction would increase the cost by approximately 1%. However, the reduction in maintenance costs will, within the first year, be equal to or greater than the added original cost. Thus, this increased investment is amortized within one year after construction and each succeeding year results in a savings of approximately 1% of the original cost per year. Furthermore, this added cost is justifiable to insure good radio reception during a national emergency or to eliminate the possible misfire of a sensitive electronic relay at an inopportune time, etc.

The above justification cannot reasonably be evaluated in dollars, but is, as is a well known fact, of enormous intangible value.

9-03 Existing Transmission Lines. The cost of re-insulating and replacing hardware on an existing transmission line is estimated to be \$1500.00 per mile. This estimate was made assuming a 45 Kv line replacement of pin type insulators, and a span length of 250 feet. It was further assumed that this line was rebuilt to conform with the interference free criteria, as outlined in this report.

However, this total cost cannot be considered as the cost of interference proofing the transmission line. Approximately

95% of the pin type insulators may be salvaged for replacement use in areas where radio interference control is not a critical problem. Thus, the value of these salvaged insulators, \$500.00 per mile, may be deducted from the gross. The resulting net cost, \$1000.00 per mile is the true cost of interference proofing an existing transmission line. This expense is justifiable, for the reasons as outlined in Section 9-02, by the tremendous value of the intangibles concerned. Furthermore, this net cost of \$1000.00 per mile, is partially justifiable on an economic basis. The radio interference proofing of the transmission line will decrease maintenance costs by reducing the necessity for retightening hardware periodically. This maintenance saving is estimated to be approximately \$100.00 per mile per year. Thus, within a 10 year period, the investment will amortize itself and result in a savings during the rest of the service life.

9-04 Transmission Line Patrols. Periodic patrols of the power and transmission system are recommended in this report for locating radio interference sources. These patrols are the only recommendation which may be over and above normal operating procedures. It should be pointed out, however, that some of the more progressive utility companies have initiated, on their own, a program for patrolling their systems lines. This operation fulfills a two-fold function of interference location and of preventive maintenance against power outages. By locating and eliminating the interference sources, "faults" which probably would develop to line outages are also located as they are generally one and the same point. Thus, these "faults" are repaired before failure actually occurs. These companies have found that the reduction in customer complaints, concerning radio interference or the increased goodwill coupled with the reduction in maintenance costs is sufficient to warrant this patrolling operation.

SECTION 10. QUALITY CONTROL OF TRANSMISSION LINE COMPONENTS.

10-01 General. "Prevention is easier than cure" is an old axiom which very appropriately applies to radio interference reduction. In the construction of an overhead line, every care can be taken with the details of construction and still the line may not be interference-free. This could be possible if the component parts on the line were not pretested to ensure their conformity to a specification. The National Electric Manufacturers Association and The American Standards Association have established a method of testing line components and have established the limits of interference for major component parts.

10-02 Method of Measurement. A standard method of testing major line components has been devised and accepted by the power utility industry and manufacturers of power utility equipment. This method is described in detail in "Methods of Measuring Radio Noise," NEMA Pub. No. 107. This publication is a report by the Joint Coordination Committee on Radio Reception of EEI, NEMA, and RMA and can be obtained from The National Electrical Manufacturers Association, 155 East 44th. Street, New York, New York.

10-03 Limits of Interference. Voltage of testing and limits of radio interference have been established by NEMA and ASA. The NEMA standards which should be followed are: Wet-Process Porcelain Insulators, publication numbers 140, 145 and 147; Transformers, publication numbers TR 1 and TR 2; Power Circuit Breakers, SG 4; Lightning Arresters, LA 1 to LA 5; and Coupling Capacitors, SG 11. The American Standards Association publication, American Standard Insulator Tests, publication number C 29.1 - 1944, should be adhered to. This publication can be obtained from The American Standards Association, Inc., 70 East 45th. Street, New York, New York.

10-04 Recommendation. All apparatus should conform to both NEMA and ASA standards where applicable. This would assure that the components on the overhead line meet a specification which has proven itself throughout the power utility industry.

The radio interference limits established by these associations have resulted from much study. Their main purpose is to maintain the interference level from transmission lines at a level low enough so as not to interfere with radio or television broadcasts. The limits are at a practical level which can be complied with by the manufacturers.

SECTION 11. RECOMMENDED SPECIFICATION

Interference Reduction, Overhead transmission lines, Construction. 12Kv to 69Kv.

- 1 Scope.
 - 1.1 This specification covers the materials and methods for use in the construction or re-building of an overhead transmission line for the maximum practical reduction in radio interference.
- 2 Applicable Specifications, Standards, Drawings and Publications.
 - 2.1 Limits of interference from transmission lines shall be as specified in report of Phase III, Contract NOy-88454.
 - 2.2 These are not complete specifications for construction of overhead lines but are requirements which are most important for the reduction of radio interference. Conditions not covered herein shall be governed by the appropriate requirements of the National Electrical Safety Code or other requirements not principally associated with radio interference. The lawful requirements of state or local authorities shall govern where they exceed those contained in these specifications.
- 3 Explanation of Terms.
 - 3.1 Radio interference is defined as undesired conducted or radiated electrical disturbances (for limit see Phase III report) which may interfere with the operation of electrical or electronic communication equipment or other electronic equipment.
 - 3.2 Effectively Grounded means permanently connected to earth through the specified impedance having sufficient current carrying capacity to prevent the building up of voltages which under the conditions may result in undue hazard.
 - 3.3 Voltage (of a circuit) means the greatest effective difference of potential between any two conductors of the circuit concerned.

- 4
4.1 Conductors.
Size. The conductors specified shall have the largest diameter that can be economically justified.
- 4.2 Splices. Conductor splices shall be made with pressure sleeves or automatic splices of the same metal as the outer portion of the conductor.
- 4.3 Spacing. Conductors shall be spaced as close together as economy of power and safety will permit.
- 4.4 Insulated Conductors. If insulated conductors are used, the insulation shall be stripped at insulators and dead-ends before installation of tie wire or clamps.
- 5
5.1 Insulators.
Type. All insulators shall be post type or suspension type. Clamp-top, post type insulators shall be used above 23 Kv. If suspension insulators are used, each insulator must be weight loaded (340# minimum) to assure continuous tension and good electrical contact between the components
- 5.2 Rating. Insulators shall be selected for the proper voltage rating (see Section 3.3) except, in contaminated areas, insulators shall exceed normal insulation by a minimum of 33 1/3% and be of the fog type.
- 5.3 Testing. Tests, for radio interference of insulators shall be made by the purchaser in accordance with NEMA standards No. 145-1952 for post type insulators and No. 140-1952 for suspension type insulators or latest revision thereof
- 6 Tie Wires. Tie wires when used shall be of the preformed type and shall be installed in accordance with figure 3, with special attention given to avoiding sharp points and loose ends.
- 7 Support Construction. All poles, cross-arms and cross-arm braces shall be of wood.
- 8
8.1 Hardware.
Type. In normal atmospheres, static-proofed, hot dipped galvanized malleable iron, carbon steel or low alloy steel hardware shall be used.

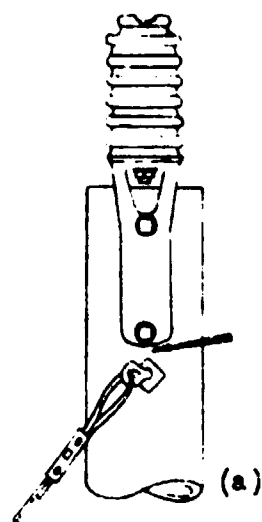
- Lock washers or lock nuts shall be used on all bolted connections.
Note: Spring type lock washers are preferred.
- 8.2 Installation. All hardware shall be spaced at least 2" apart with one side of the nut and washer paralleling a side of adjacent metal parts.
9. Grounding.
- 9.1 Ground Wire. Ground wires shall be kept clear of the conductor and all hardware and shall be covered with a wooden molding from 3' below the cross-arm to the groundlevel.
- 9.2 Ground Rods. Galvanized steel or zinc ground rods shall be used and shall be sufficient in number to cause an effective ground (see section 3.2) not exceeding 10 ohms impedance.
- 9.3 Connection. The ground wire shall be connected to the ground rods with pressure connectors. The ground wire underground shall be taped, with moisture resistant, rubber tape, from 1 foot above the ground level to and including the connection.
- 10 Guy Wires. Guy wires shall be kept clear of all other metal parts and the guy wire bracket shall be clear (2" minimum) and edges parallel to adjoining hardware. Use separate guy plates for each guy wire.
- 11 Pole Top Switches. All connections on pole top switches shall be tightened before installation, all sharp points shall be rounded, and switches shall be placed a minimum of 2" away from all other unbonded metal on the pole. Switch contacts shall be clean and shall make a positive connection.
- 12 Lightning Arrestors. All lightning arrestors shall be of the radio-interference-free type.
- 13 Substations.
- 13.1 General. Substations shall be located away from areas of possible contamination. Exit low voltage lines underground, from the substation at a minimum angle of 90° to the high voltage line; or

- exit low voltage line above ground, on an extension of the line made by the entering high voltage line. In either case, the exit shall continue a minimum of 200' in the direction indicated as shown in figures 6, 6A, 7, 7A.
- 13.2 Transformers. All transformers shall be of the oil-filled type and shall be effectively grounded (see section 3.2) by a short strap through an impedance not exceeding 3 ohms. All transformers shall be tested for radio interference, by the purchaser in accordance with NEMA standards, publication No. TR1-1954, or latest revision thereof.
- 13.3 Bushings. All bushings shall be of the radio interference free type.
- 13.4 Fuses. Fuses with corrosion resisting ferrules shall be used and shall fit tightly in the clips.
- 14 Conducted Attenuation.
- 14.1 Choke Coils. Radio frequency choke coils may be installed to attenuate conducted interference.
- 14.2 Underground. Placing the transmission line underground, as an alternate for choke coils, will also attenuate conducted interference. This system requires a minimum length of 100' and the effective ground (see section 3.2), of the cable sheath not to exceed 3 ohms impedance.
- 15 Corrosion Resistance.
- 15.1 Environment. In corrosive atmospheres, corrosion resistant metals shall be specified for tie wires, hardware and all other metal parts.
- 15.2 Galvanic. Connections, whenever possible, shall be made of similar metals. If dissimilar metals are connected, a special connector designed for dissimilar metal connection shall be used.
- 16 Maintenance.
- 16.1 Line. All foreign material such as hay wire, kite strings, etc. shall be kept off the line. Guy wires shall be kept under tension at all times.
- 16.2 Miscellaneous. Trees and shrubbery shall be trimmed to prevent conductors, guy wires or ground wires from brushing them. Conductors shall have a minimum of 3' clearance from any

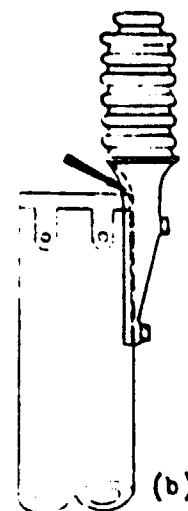
16.3

tree or shrub.

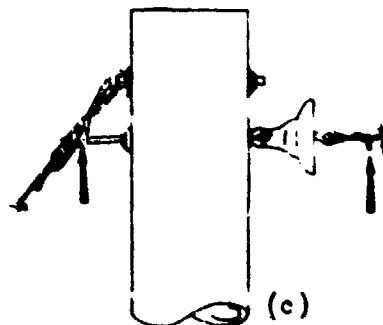
Line Patrols. A patrol of the system, following the procedure outlined in Section 7, shall be performed immediately after the line has been constructed, rebuilt or after any major repair. A patrol shall also be performed after any power outages or severe electrical storm. The maximum interval between patrols shall be two (2) months.



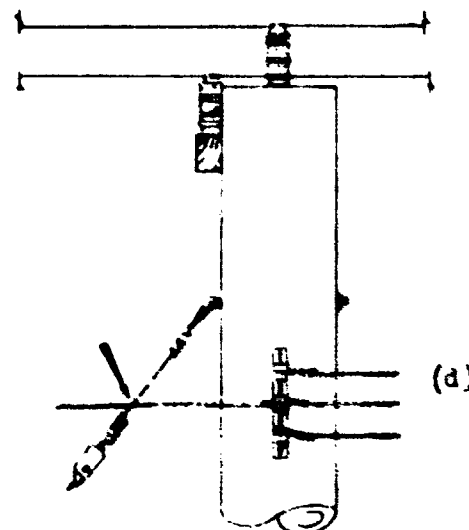
Guy wire bracket too close to insulator bracket



Pole top cap not in contact with insulator bracket



Guy wire too close to thru bolt. Sharp point on dead end tie.

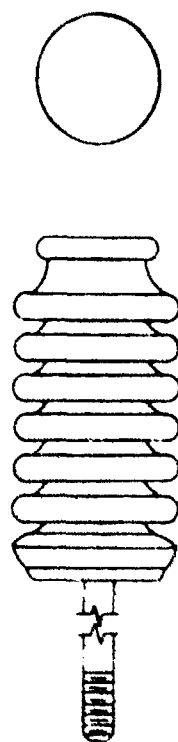


Guy wire brushing against distribution line.

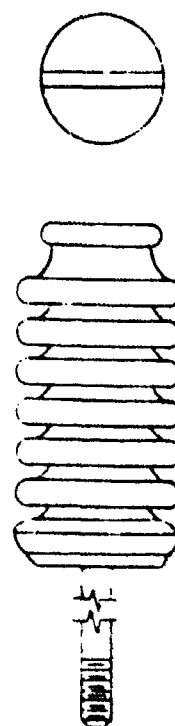
FIGURE 1

IMPROPER CONSTRUCTION PRACTICES

TYPICAL INTERFERENCE GENERATION POINTS



Side Grove



Top Grove



Clamp Top

FIGURE 2
THREE TYPES OF POST INSULATORS

THE HINGHAM CORPORATION
ENGINEERS
Francis Palmer Building
Detroit 1, Michigan

Bend end tight
against wire.
1" Dia.
Twist
(1 revolution) -> Serve 1-Turn

Twist 1 1/2 revolutions
tight to insulator.

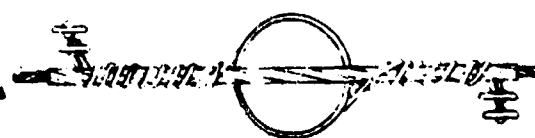
TIE WIRE

a.

b.

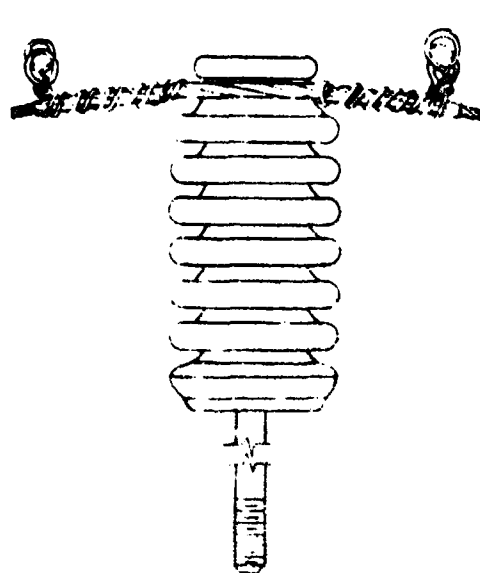


c.

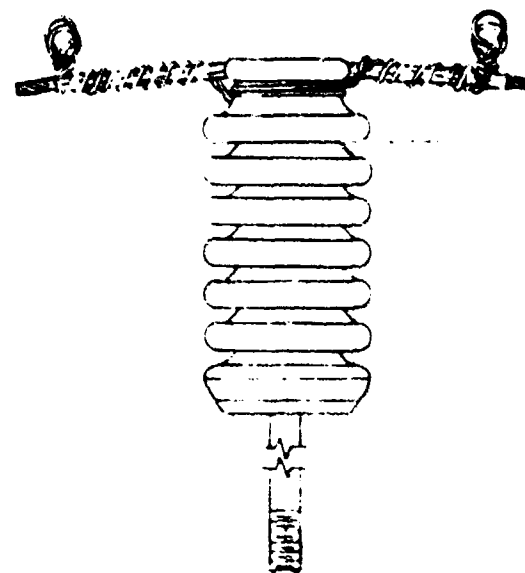


e.

Armor rods not normally used on copper.



d.



f.

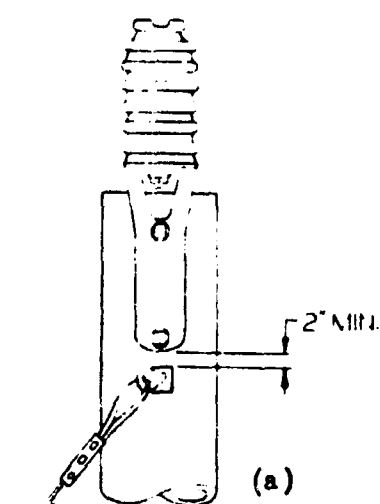
SIDE GROOVE LINE TIE.

TOP GROOVE LINE TIE.

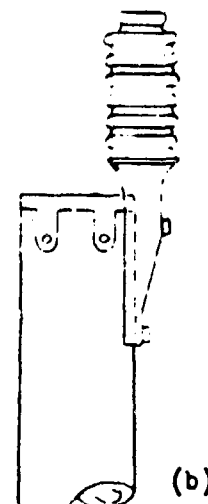
THE HINGEMAN CORPORATION
ENGINEERS
Francis Palms Building
Detroit 1, Michigan

FIGURE 3

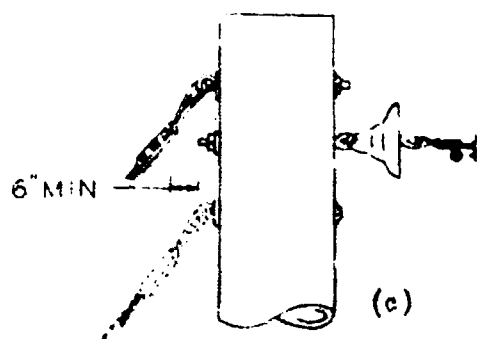
SUBTRANSMISSION TIES AND SUPPORTS



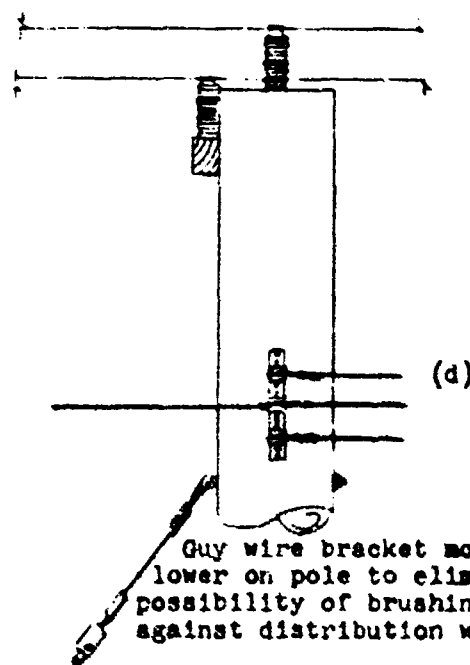
Guy wire bracket parallel to insulator bracket and sufficient distance away.



Pole top cap bonded to insulator bracket.



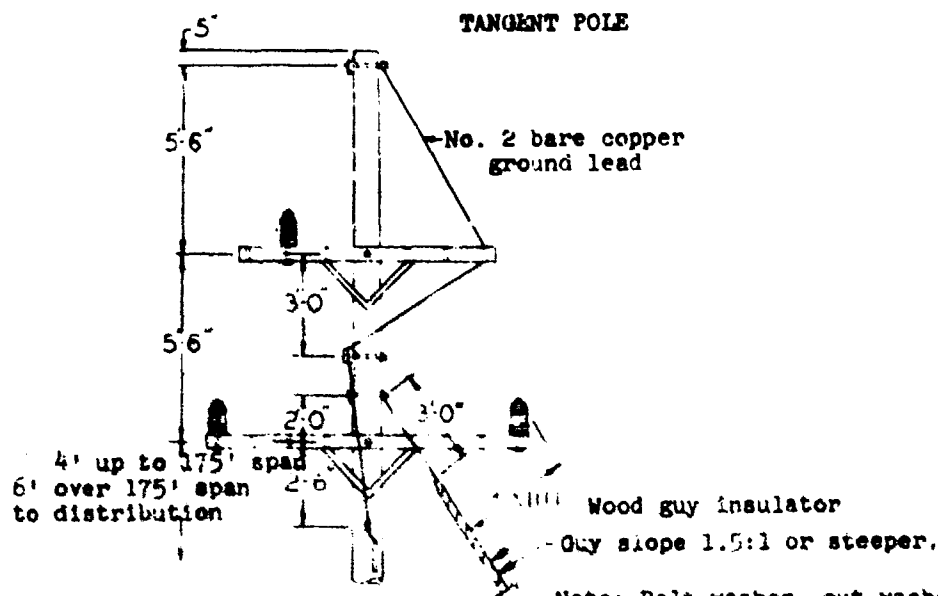
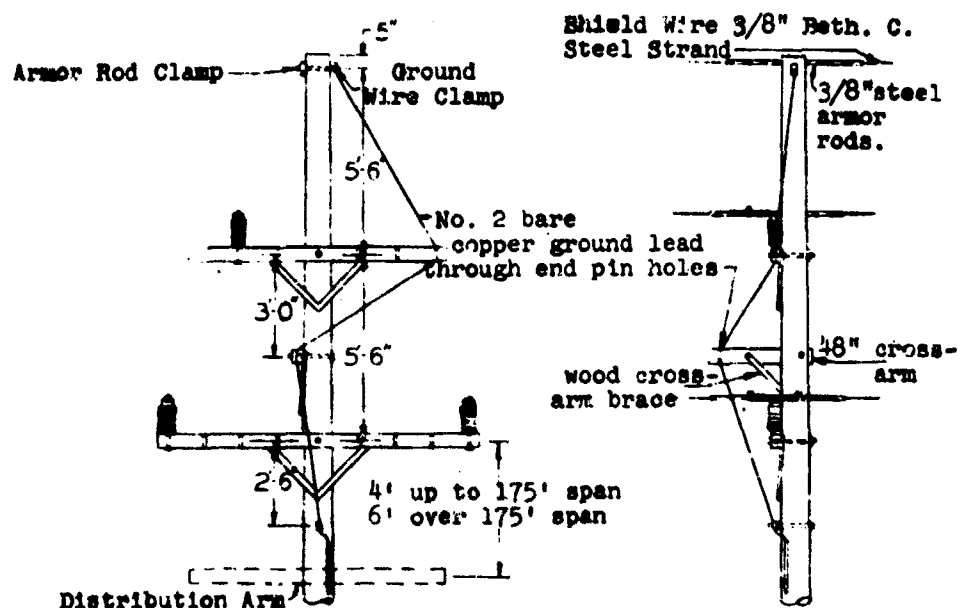
Guy wire spaced either sufficient distance from thru bolt or moved lower on pole. Dead end tie looped.



Guy wire bracket moved lower on pole to eliminate possibility of brushing against distribution wires.

FIGURE 4

PROPER CONSTRUCTION PRACTICES

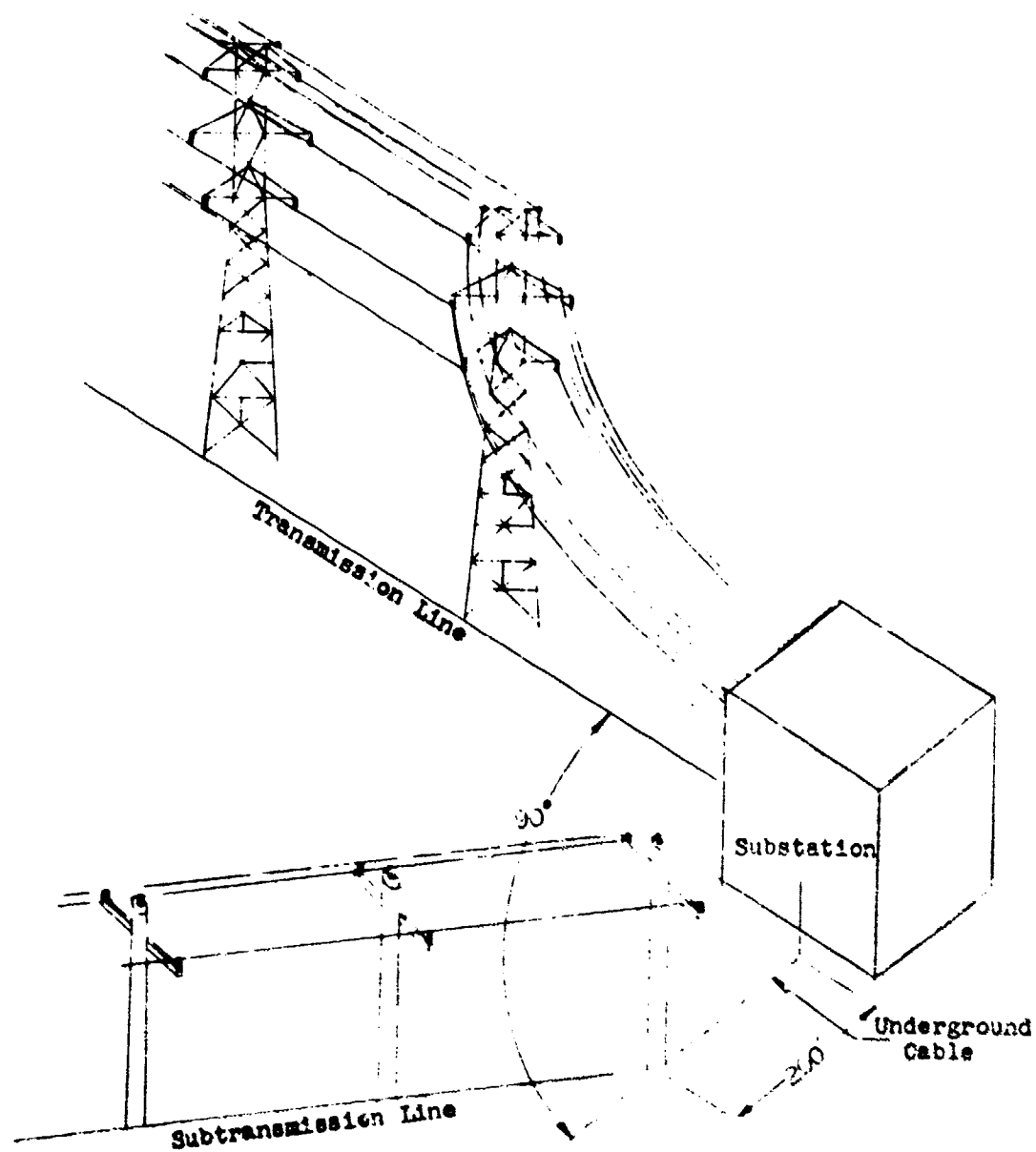


ANGLE POLE

FIGURE 5

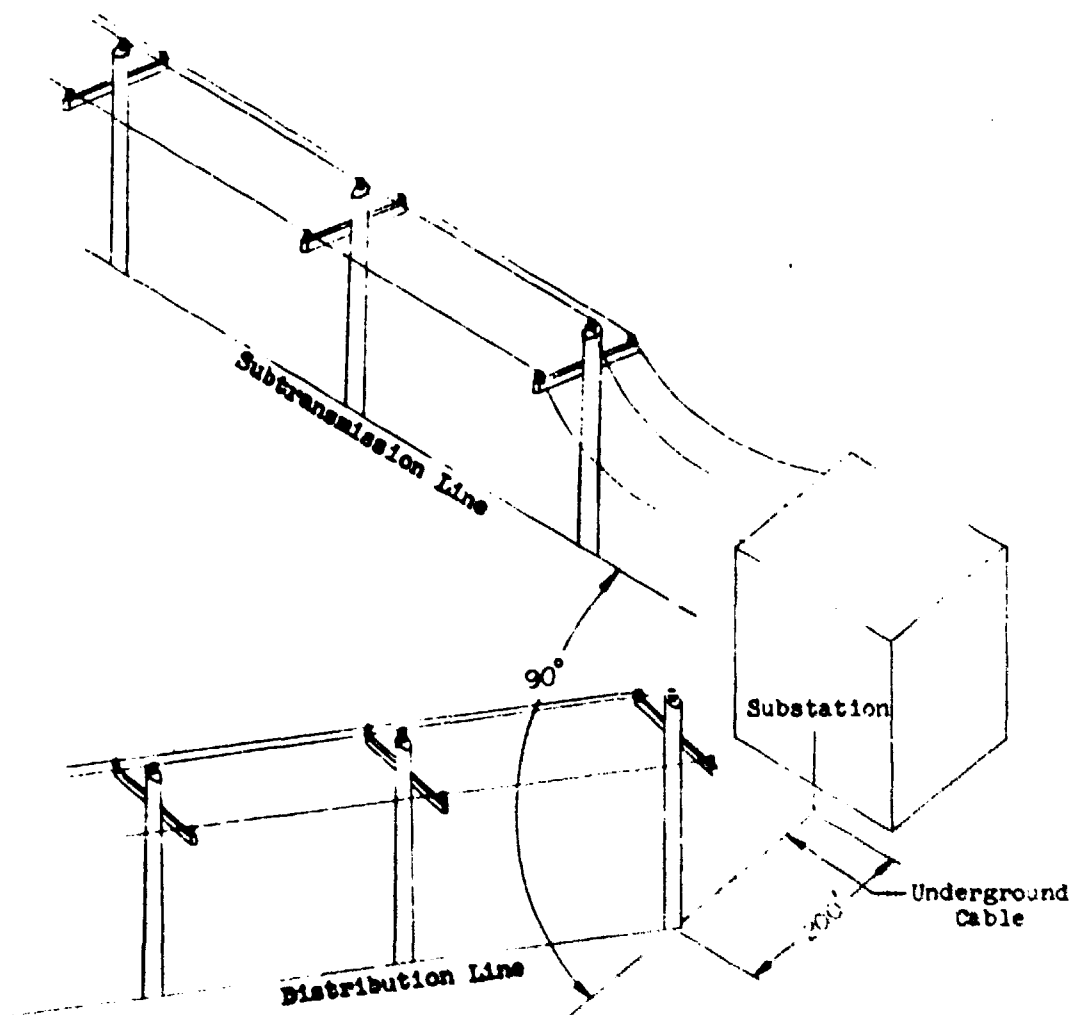
THE KINCHEMAN CORPORATION
ENGINEERS
Francis Palmer Building
Detroit 1, Michigan

SINGLE CIRCUIT SHIELD WIRE
RECOMMENDED CONSTRUCTION



THE HINGHAM CORPORATION
ENGINEERS
Francis Palmer Building
Detroit 1, Michigan

FIGURE 6
UNDERGROUND EXIT OF SUBTRANSMISSION LINE



THE HINGEMAN CORPORATION
ENGINEERS
Francis Palmer Building
Detroit 1, Michigan

FIGURE 6 A

UNDERGROUND EXIT OF DISTRIBUTION LINES.

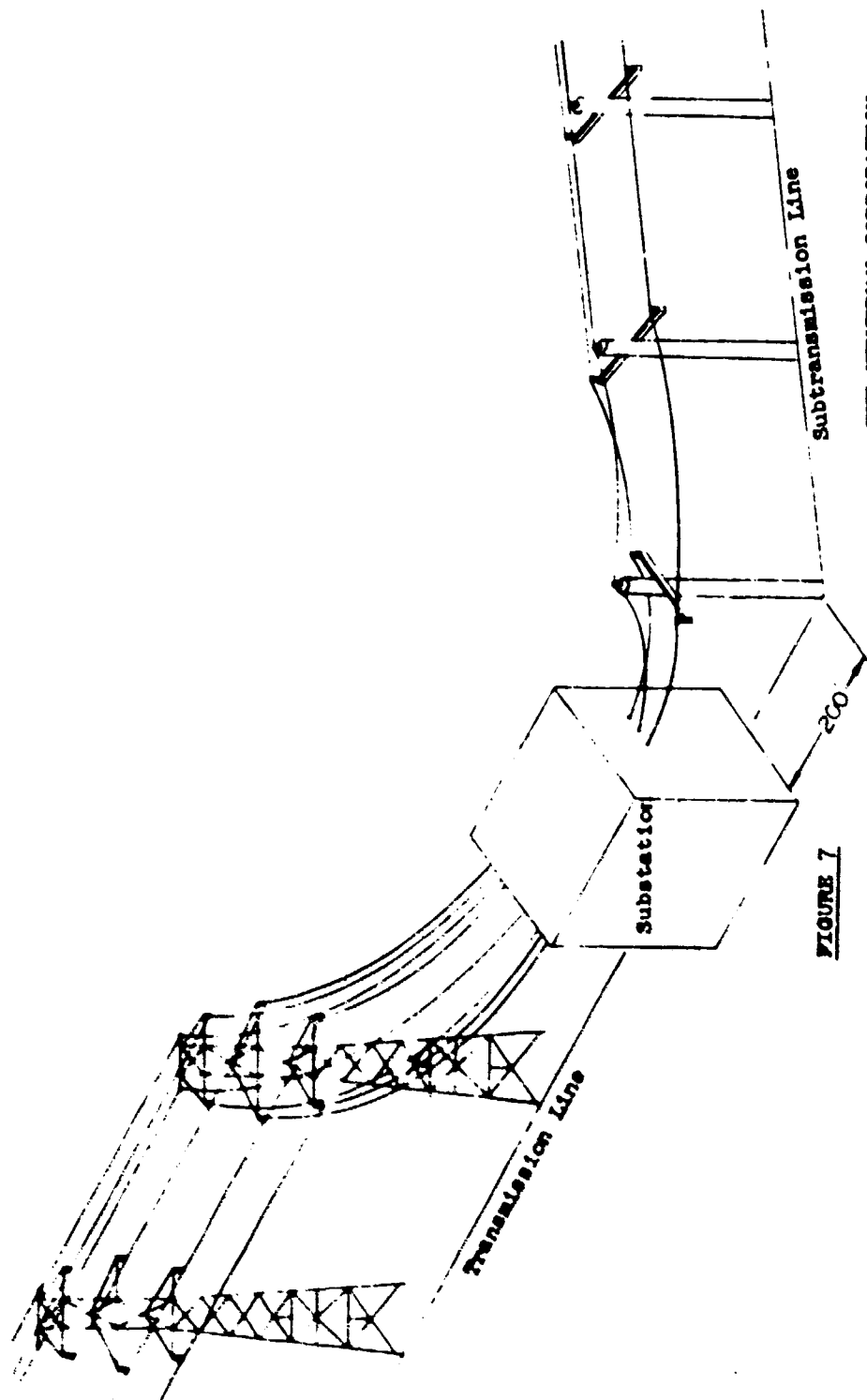


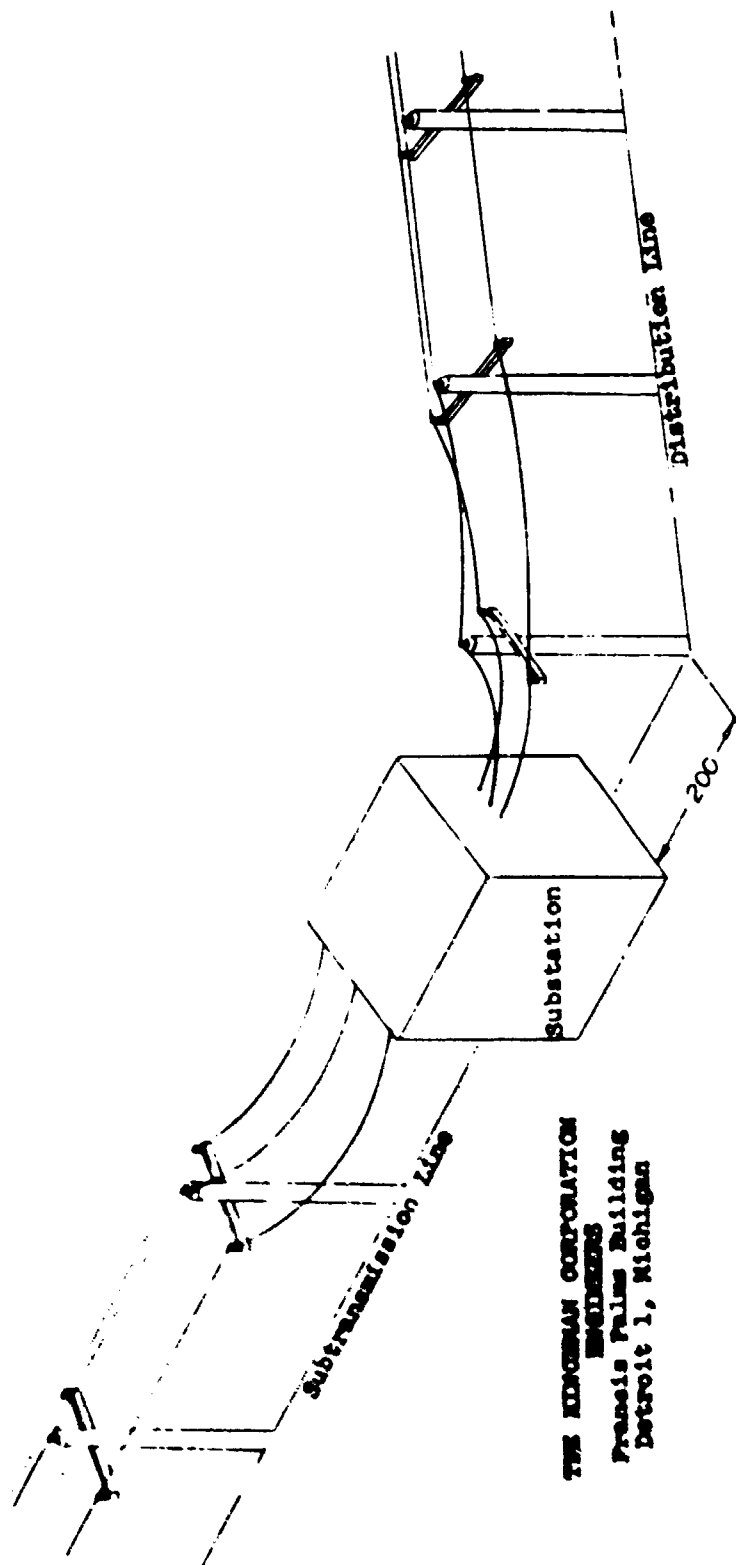
FIGURE 7

OVERHEAD EXIT OF SUBTRANSMISSION LINE

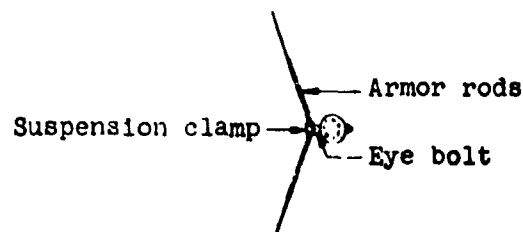
**THE HINGEMAN CORPORATION
ENGINEERS
Francis Palmer Building
Detroit 1, Michigan**

FIGURE 7 A

OVERHEAD EXIT OF DISTRIBUTION LINES.

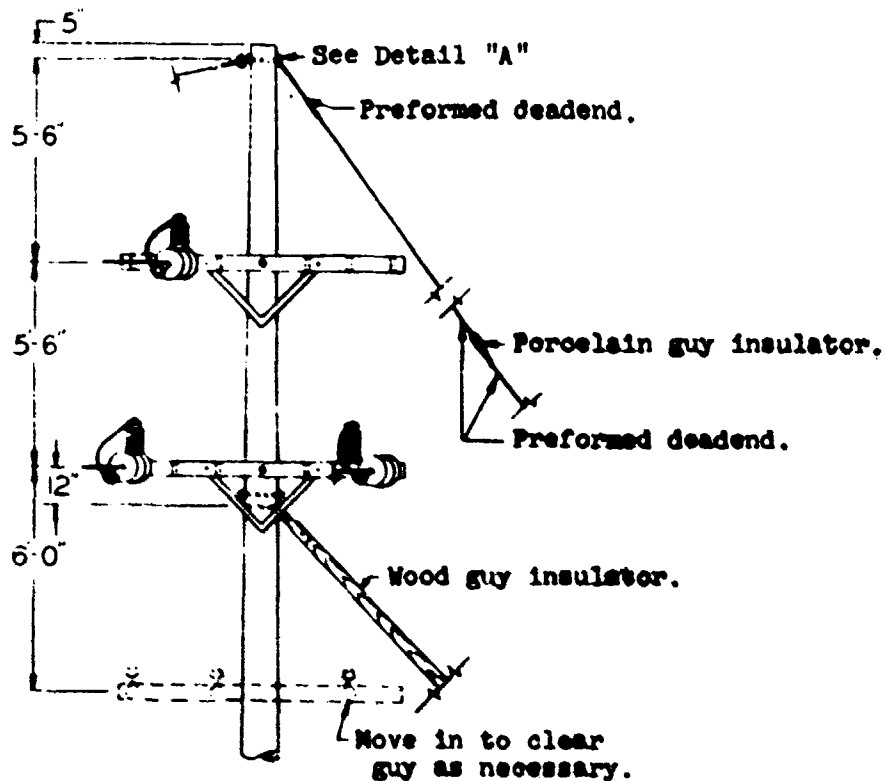


THE KINGMAN CORPORATION
ENGINEERS
Francis Palmer Building
Detroit 1, Michigan



SHIELD WIRE PULL OFF

Detail "A"



ANGLE POLE UP TO 60°

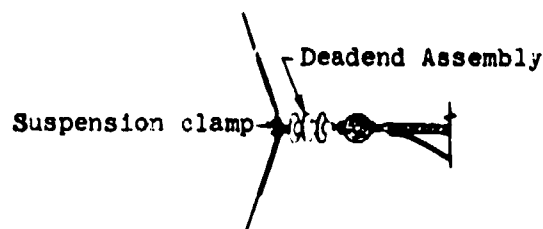
Note: Bolt-washer, nut-washer or spring washer, and lock nut to be used for all bolted connections, see Figure 11.

FIGURE 8

SINGLE CIRCUIT SHIELD WIRE

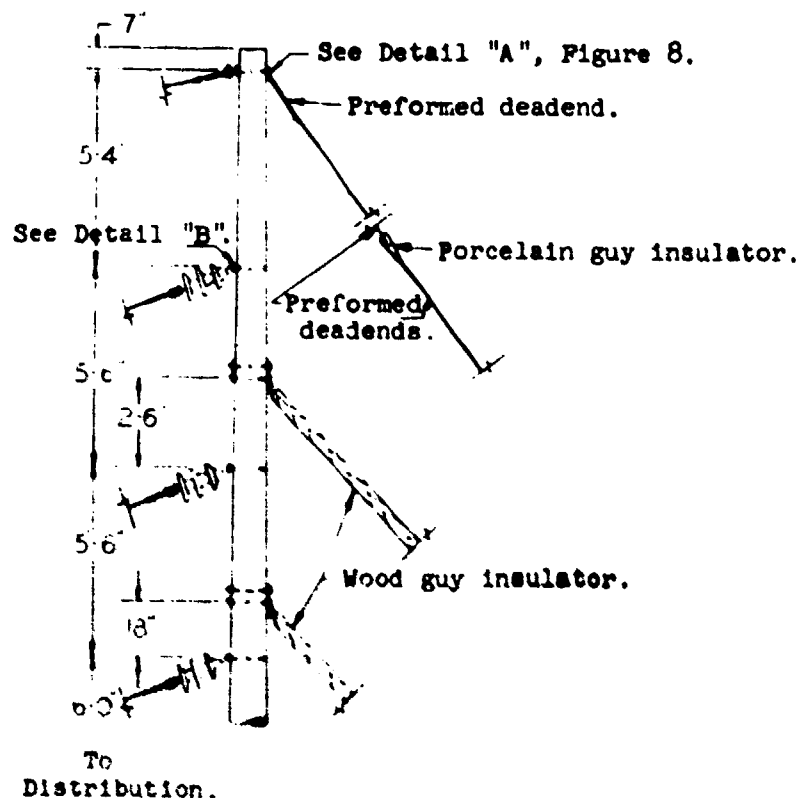
RECOMMENDED CONSTRUCTION

THE HINGEMAN CORPORATION
ENGINEERS
Francis Palmer Building
Detroit 1, Michigan



CONDUCTOR PULL OFF

Detail "B"



Note: Bolt-washer, nut-washer, spring washer, and lock nut to be used for all bolted connections, See Figure 11.

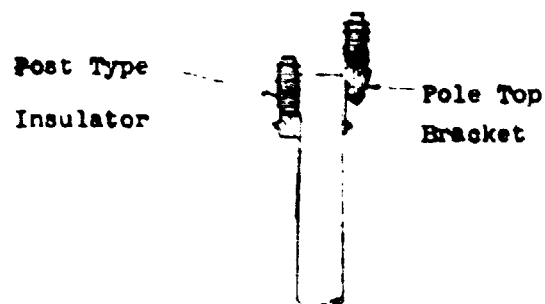
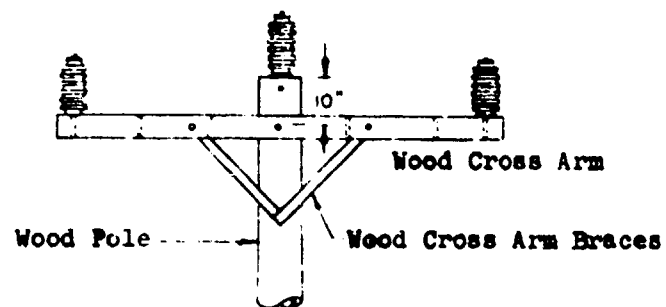
ANGLE POLE UP TO 60°

FIGURE 8 A

SINGLE CIRCUIT SHIELD WIRE

RECOMMENDED CONSTRUCTION

THE HINCHEMAN CORPORATION
ENGINEERS
Francis Palms Building
Detroit 1, Michigan



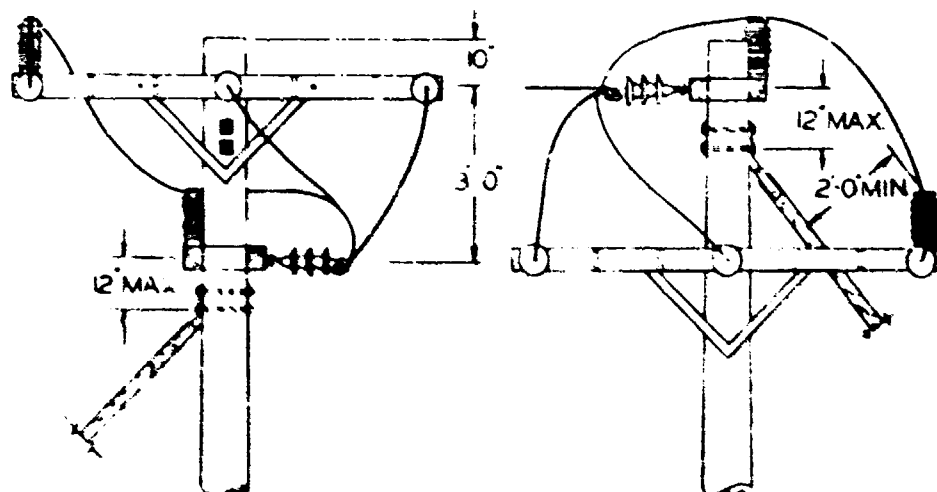
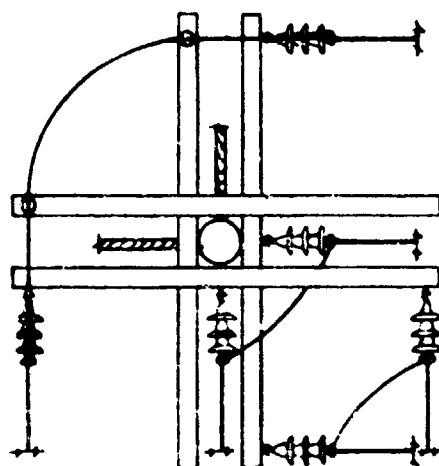
Note: Bolt-washer, nut-washer or spring washer, and lock nut to be used for all bolted connections, see Figure 11.

THE KINCHEMAN CORPORATION
ENGINEERS
Francis Palmer Building
Detroit 1, Michigan

FIGURE 9

LINE POLE

SINGLE CIRCUIT FLAT CONSTRUCTION



Note: Bolt-washer, nut-washer or spring washer, and lock nut to be used for all bolted connections. See Figure 11.

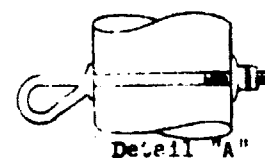
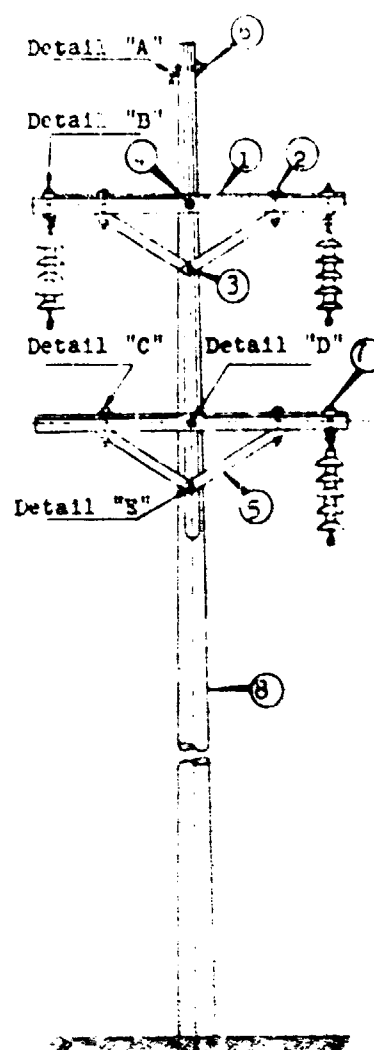
FIGURE 10

CORNER POLE

SINGLE CIRCUIT PLAT CONSTRUCTION

THE KINGMAN CORPORATION
ENGINEERS

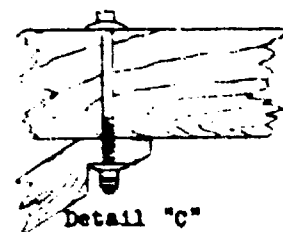
Francis Palmer Building
Detroit 1, Michigan



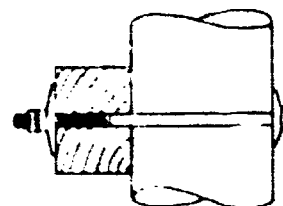
Detail "A"



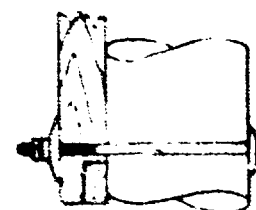
Detail "B"



Detail "C"



Detail "D"



Detail "E"

THE KINCHEMAN CORPORATION
ENGINEERS
Francis Palmer Building
Detroit 1, Michigan

| ITEM | DESCRIPTION | QTY |
|------|---|-----|
| 1 | Arm, Wood; 3 3/4" x 5 1/4" x 9'-0" | 2 |
| 2 | Bolt, Shoulder Machine; 1/2" x 9" with washer nut & lock nut | 4 |
| 3 | Bolt, Shoulder Machine; 5/8" x 12" with washer nut & lock nut | 2 |
| 4 | Bolt, shoulder Machine; 3/4" x 18" with washer nut & lock nut | 2 |
| 5 | Brace, Wood; 60" (without metal fastenings) | 2 |
| 6 | Bracket, shoulder; 5/8" x 10" with washer nut and lock nut | 1 |
| 7 | Bolt, shoulder eye; 5/8" with threaded saddle washer & standard nut | 1 |
| 8 | Pole, height and class as required | 1 |

FIGURE 11

GOOD ENGINEERING CONSTRUCTION PRACTICES USING
SUSPENSION INSULATORS

BIBLIOGRAPHY

- 1 "Electrical Transmission and Distribution Reference Book", Central Station Engineers, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania.
- 2 "Federal Register", Part 15.
- 3 "Report of a Review of Past and Current Work on Electromagnetic Interference Voltage from Electric Power Transmission Lines", The Hinchman Corporation, Contract NOy-88454, 23 November 1955.
- 4 "Report of Field Study of Electromagnetic Interference from High Voltage Transmission Lines, Phase II", The Hinchman Corporation, Contract NOy-88454, 22 July 1957.
- 5 "Report and Criteria, Method of Measurement and Recommended Allowable Limits of Electromagnetic Interference Voltages from High Voltage Transmission Lines", The Hinchman Corporation, Contract NOy-88454, Phase III, 28 October 1957.
- 6 Sanford, T. E., and Weise, Willard. "A Review of Radio Interference Investigation", Electrical Engineering, October 1937, pp. 1248-52.
- 7 Foust, C. M. and Frick, C. W. "Measurements Pertaining to the Co-ordination of Radio Reception with Power Apparatus and Systems", AIEE Transactions, Volume 62, June 1943.
- 8 Atta, E. V. and White, E. L. "Radio Interference from Line Insulators", Journal AIEE, September 1929, pp. 682-86.
- 9 "Radio Interference Suppression and Elimination", Radio Interference Specialty Company.
- 10 "A Practical Handbook for Location and Prevention of Radio Interference from Overhead Power Lines", U. S. Naval Civil Engineering Research and Evaluation Laboratory, Project NY 411 002-1, 21 November 1956.
- 11 Newell, H. H. and Warburton, F. W., "Variations in Radio and Television Interference from Transmission Lines", October 20, 1955, Technical Paper No. 56-223. AIEE Transactions.

- 12 "Suppression of Inductive Interference", Canadian Department of Transport, Telecommunications Division, SII-11-8, July 28, 1954.
- 13 "Catalog, Thorex Dynagap, Lightning Arresters", Publication No. 1366-H, Ohio Brass Company, Mansfield, Ohio.
- 14 "Electric Power Distribution" Chapter 8 of Power Generation and Distribution, Department of the Navy, Bureau of Yards and Docks, Technical Publication, Navdocks, TP-PU-3, 15 October 1955.
- 15 Bardeen, A. W. and Sheadel, J. M. "Corrosion as It Affects Insulator and Conductor Hardware", October 19, 1955, Technical Paper No. 56-230. AIEE Transactions.
- 16 "Incidence and Nature of Power Line Interference", Canadian Department of Transport, Telecommunications Division, 5-10-594, July 15, 1957.
- 17 Whisler, G. M. "Treating Insulators to Reduce Radio Interference", Electrical West, Volume 77, No. 5, November 1935.
- 18 Aggers, C. V. "Methods of Controlling Radio Interference" Transactions AIEE, April 1940, Volume 59, pp. 193-9.
- 19 McMillan, P. O. "Asphalt Emulsion Treatment Prevents Radio Interference", Electrical West, Volume 74, No. 1 January 1935 pp. 16-19.
- 20 Rorden, H. L. "Radio-Noise Influence of 230 Kv Lines", AIEE Transactions, January 1947, Technical Paper No. 47-92.
- 21 Sleman, Gordon R. "Radio Influence from High Voltage Corona" AIEE Transactions, Volume 68, February 1949.
- 22 Sterba and Feldman, Proceedings I.R.E., Volume 20, July 1932.
- 23 Blake, L. V. "Prevention Easier Than Cure of Radio Interference". Electrical World, September 21, 1940, pp. 61-63.

- 24 Schulz, W. A. "Can Radio Noise From Loose Hardware be Eliminated". Electric Light and Power, October 1937, pp. 59-60.
- 25 "Investigation and Suppression of Radio Interference from Power Lines and Distribution Systems". Canadian Department of Transport, Air Services Telecommunications Division, SII-10-46, 4 September 1951, Reprint 1 June 1955.
- 26 "Catalog, Apparatus Bushing Reference Book" GET 2525, General Electric Corporation, Power Transformer Department, Pittsfield, Mass.
- 27 Zastrow, O. W. "Underground Corrosion on Rural Distribution Lines". Electrical Engineering, May 1955, p. 417.
- 28 "Laboratory and Field Tests on Risco Radio Interference Choke Coils for Overhead Power Lines". U. S. Naval Civil Engineering Research and Evaluation Laboratory, Project NY 411 002-1, Technical Note N-282, 26 December 1956.
- 29 Kalb, H. N. "Isolating Radio Interference". Electrical World, 2 March 1935.
- 30 Mabry, F. S. "Eliminating Radio Interference from Power Lines". The Electric Journal, April 1930, pp. 211-12.
- 31 "Albin, A. L. and H. M. Sachs, "Design of Electronic Equipment For Radio Interference Reduction". AIEE Transactions, February 15, 1950, Technical Paper No. 56-257.
- 32 Allen, James G. "Radio Interference", Proceedings of the Institute of Radio Engineers, May 1929, Volume 17, Number 5, pp. 882-91.
- 33 McMillan, F. O. "Some Characteristics of A. C. Conductor Corona". Electrical Engineering, Volume 54, March 1935, pp. 282-92.
- 34 Miller, Jr. C. J. "Behavior of High Voltage Insulators on Radio Test". Electrical World, March 25, 1939, pp. 45-48.

- 35 Gilchrest, G. I. "Treating Insulators to Reduce Radio Interference", Electrical Engineering, June 1934, pp. 889-902.
- 36 McMillan, F. O. "Radio Interference from Insulator Corona". AIEE Transactions, January 1932, pp. 385-91.
- 37 Barrow, G. W. "Eliminating Radio Interference from Pin Type Insulators", Electrical World, December 10, 1932, p. 787.
- 38 Crooks, J. S. and H. A. Baldwin and L. E. Bates. "Improved Hardware Cuts Radio Interference". Electrical World, July 12, 1941.
- 39 Leslie, J. R. and P. M. Waddington, "Field Studies of Noise at Television Frequencies from Power Circuits". AIEE Transactions, October 17, 1955, Technical Paper No. 56-221.
- 40 McMillan, F. O. "The Coordination of High-Voltage Transmission Lines with Radio". Foreign Systems Coordination Committee Publication, April 1932, pp. 15-37.
- 41 Greene, F. L. and S. C. Bartlett, "Methods and Equipment for Tracing Television Interference". Ohio Power Company.
- 42 "Television Interference". Remington Rand Laboratory of Advance Research, South Norwalk, Conn.
- 43 "Testing Power Line Apparatus for Radio Noise". U. S. Department of Agriculture, Rural Electrification Administration, March 1954, Bulletin 169-24.
- 44 "Methods of Measuring Radio Noise". Joint Coordination Committee on Radio Reception of E.E.I., N.E.M.A., and R.M.A., February 1940.
- 45 Aggers, C. V., Foster, D. E. and C. S. Young. "Instruments and Methods of Measuring Radio Noise". AIEE Transactions, March 1940, Volume 59.

- 46 "The Radio Engineering Handbook". Keith Henney, Editor-in-Chief, Third Edition, McGraw-Hill Book Company, Inc., New York, 1941.
- 47 "Standard Handbook for Electrical Engineers", Archer E. Knowlton, Editor-in-Chief, Seventh Edition, McGraw-Hill Book Company, Inc., New York, 1941.

* Numbers 32 through 47 are not used as references in this report, but are given as added background material to assist the reader in any additional study.